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Spatial Relationships and Osseous Morphology Associated with Adolescent TMJ Disc Status

by

Robert D. Kinniburgh ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment

of the requirements for the degree of Master of Science

in

Orthodontics

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Dedication

This work is dedicated to my lovely wife, Shannon, for her patience, support, and understanding over the past thirty months.

Abstract

The objectives of this retrospective study were twofold. The first was to determine differences in spatial relations and osseous morphology between temporomandibular joints with normal and anterior disc position. The second was to determine the predictive capability of osseous temporomandibular characteristics for disc position and deformation. A total of thirteen tomographic variables were measured from pre-orthodontic tomograms of 335 temporomandibular joints in 175 subjects (106 female and 69 male) between the ages of 7.27 - 20.0 years (mean age 13.08 yrs). Independent samples t-tests revealed significant differences for all measures of joint space, condylar position, and morphology of the articular eminence ($p < 0.05$) between joints with normal disc position and with full anterior disc displacement. Stepwise linear regression indicated that measures of joint space are the most predictive while measures of condylar morphology are least predictive of joint status. This study indicated that measures of joint space and eminence morphology are suggestive of internal derangement but not diagnostic.

Acknowledegement

A special thanks to Dr. Brian Nebbe for his time and sharing of knowledge during the inception and execution of this project.

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Chapter One

Introduction

And

Literature Review

1.1 - Introduction

The identification of existing abnormalities of the temporomandibular joint or predisposing factors in temporomandibular disorders (TMD) is an important step in the collection of a diagnostic data base for the orthodontist. The identification of TMD is valuable in that it may allow the orthodontist to forewarn the patient of potential complications and may allow the selection of the most appropriate form of mechanotherapy for the individual patient. This information may also be useful in the determination of the etiology of several malocclusions. Literature suggests that temporomandibular disorders, and more specifically internal derangement, may be associated with the development of skeletal malocclusion[1-3].

Clinical assessment of the temporomandibular joints may be enhanced through imaging. Tomography, the imaging of choice for the detection of osseous changes within the temporomandibular joint, is unable to provide soft tissue assessment. Therefore, arthrography or magnetic resonance imaging must be considered in cases of suspected internal derangement. Given the morbidity associated with arthrography and expense of magnetic resonance imaging, identification of osseous characteristics associated with internal derangement in tomographic images of the temporomandibular joint would be of value. Research has suggested that there may be changes in joint space[4-6], the condyle[5,7,8], and the articular eminence[9,10] with disc displacement. If these characteristics can be identified and used to determine joint status in the adolescent population, perhaps imaging beyond tomography may be avoided.

The primary obstacle in the assessment of condylar and temporal morphology is the quantification of dimensions for the purpose of between patient comparison and establishment of an anatomically valid reference system. As with the assessment of condylar position, the assumption that stable anatomic landmarks are available or the extrapolation of assumed reference planes is difficult to defend. Linear measurement of condylar and temporal dimension has been evaluated in sagittal tomograms using a variety of arbitrary landmarks[11,12]. This may explain why subjective evaluation of changes in condylar radiographic characteristics and size has been the primary mode of analysis[13,14]. The development of a reference system that would allow between patient comparison on an objective rather than subjective basis would limit inconsistencies that may occur with subjective evaluation and may prove to be a valuable tool for future research.

1.2 - Statement of the Problem

Without appropriate soft tissue imaging, the identification of internal derangement during adolescence is a challenge for the orthodontist. The majority of research literature which has investigated the relationship of the osseous and soft tissue structures of the temporomandibular joint has been conducted in the adult population. These studies have indicated that there may be changes in the spatial relationships and osseous tissues which are suggestive of internal derangement. Although these radiographic parameters are indicative of internal derangement, no one measure is diagnostic in osseous images.

The information available with respect to internal derangement for the adult population may not be applicable to the adolescent due to differences in the histological nature and growth characteristics of the osseous and soft tissues . The lack of information regarding the adolescent with internal derangement has created the need for study of the characteristics of the osseous tissues in normal and internally deranged temporomandibular joints in this younger age group. This data may provide clues into the predisposing factors or sequelae of internal derangement in this unique population.

1.3 - Purpose

The purpose of this retrospective research study was to examine tomographic measures of joint space, condylar position, osseous morphology and utilize the information to aid in assessing differences between normal and internally deranged joints. This will be accomplished through the investigation of tomographic images of adolescent males and females. The data obtained will be cross-referenced with data obtained from magnetic resonance imaging (MRI) for disc displacement and disc deformation from the same population. It is also the aim of this research project to determine if spatial relations and osseous morphology of the temporomandibular joint can be used to predict joint status in adolescent patients.

Through the data analysis, the findings may provide the orthodontist with a valuable diagnostic aid which may be utilized in the recognition of specific features in tomographic images which are suggestive of internal derangement. The early detection of internal derangement without the morbidity of arthrography and the expense of magnetic resonance imaging would be of great value to the orthodontic patient. In addition, the recognition of characteristics associated with internal derangement in tomographic images allows the orthodontist to choose treatment modalities which are most favorable for specific patients with compromised temporomandibular joint structure and function.

1.4 - Research Questions

1. Is there a significant difference in spatial relationships and osseous morphology of the temporomandibular joint as viewed in axially corrected sagittal tomographic images between adolescent subjects with normal superior disc position and anterior disc position?

2. Is there a relationship between joint space and osseous morphology as measured from axially corrected sagittal tomograms of adolescent patients and joint status as determined through interpretation of magnetic resonance imaging?

1.5 - Hypotheses

1. A significant difference exists for the position of the condyle, measures of joint space, and osseous morphology as viewed on tomographs for adolescent pre-orthodontic patients with normal and anterior disc position.
    a. Anterior disc position will result in significantly posteriorly positioned condyles, increased anterior joint space, and reduced superior and posterior joint space
    b. Anterior disc position will result in a significant reduction in the convexity of the anterosuperior surface of the condyle and the posterior slope of the articular eminence.
2. There is a significant relationship between measures of joint space, curvature of the anterosuperior surface of the condyle, posterior slope of the articular eminence and indicators of joint status in adolescent patients.

1.6 - Literature Review

1.6.1 - Normal Anatomy of the Temporomandibular Joint

The mandibular condyle articulates with the squamous portion of the temporal bone. The temporomandibular joint (TMJ) is formed by the condyle fitting into the glenoid fossa of the temporal bone with the articular eminence anteriorly and the squamotympanic fissure posteriorly. Interposed between the mandibular condyle and the glenoid fossa is the articular disc. Together, these three components allow the unique hinging and gliding movements of this joint.

For the condyle and the temporal bone, the articular surfaces consist of fibrous connective tissue at birth which undergoes varying degrees of metaplastic conversion to fibrocartilage during postnatal life[15]. There is no hyaline cartilage in the joint. The collagen fibers are aligned parallel to the joint surface and interlace with each other. The thickness of the condylar articular soft tissue ranges between 0.1 and 1.0 mm and is generally thickest antero-superiorly [16,17]. For the temporal bone, it is thickest at the crest of the articular tubercle and the postero-inferior slope of the eminence but is quite variable in thickness. Reported values range from 0.03 m to 1.5 mm [18]. In the non-articulating roof of the mandibular fossa, there is a thin plate of compact bone covered by a layer of fibrous connective tissue devoid of cartilage cells. This area is not suitable for loading.

The articular disc is composed of dense sheet of fibrous connective tissue and is without any vessels or nerve fibers[19]. Antero-posteriorly, it can be divided into three zones; the anterior band, the intermediate band, and the posterior band[20]. The intermediate zone is the thinnest at approximately 0.5 mm. The posterior band, slightly thicker than the anterior, is approximately 2 mm in thickness. In a normal joint, the intermediate band of the articular disc remains interposed between the anterosuperior articulating surface of the condyle and the posterior slope of the articular eminence[21]. Medio-laterally, the disc is thicker medially and takes on the shape of an arc. The average antero-posterior length of the disc is 10 mm[22]. The morphology of the disc is determined by the morphology of the mandibular fossa and condyle, but is said to have a bow tie appearance with a normal condyle-disc-fossa relationship[23]. The disc maintains this morphology unless it is altered by destructive forces or structural changes in the joint[24]. In addition to the function of normalizing the interarticular space, the disc possesses properties which promote lubrication of the articular surfaces[25].

Postero-superiorly, the disc is attached by loose fibro-elastic tissue to the squamotympanic fissure and posterior wall of the glenoid fossa[26] and is called the superior retrodiscal lamina. Postero-inferiorly, the attachment is made up mainly of fibrous tissue, inserts into the back of the mandibular condyle and is called the inferior retrodiscal lamina. Together, these two attachments make up the bilaminary zone. Loose connective tissue which is highly vascularized and innervated lies between the inferior and superior lamina[27].

Anteriorly, the disc has attachments which divide superiorly and inferiorly. Above, it is attached to the anterior margin of the articular eminence and below to the articular margin of the condyle. In addition, the disc is also attached to the fibers of the superior lateral pterygoid muscle between the superior and inferior attachments[28]. The medial and lateral attachments are to the respective poles of the condyle via the collateral or discal ligaments and divide the joint space into superior and inferior compartments.

There are four other ligaments involved with the function of the TMJ[29]. The capsular ligament is attached superiorly to the temporal bone along the articular surfaces of the mandibular fossa and inferiorly to the neck of the condyle. This serves to resist any forces that may tend to separate the articular surfaces and to retain the synovial fluid of the joint. The temporomandibular ligament is divided into the outer oblique portion and the inner horizontal portion. The outer oblique component reaches from the outer surface of the articular tubercle and zygomatic process to the outer surface of the condylar neck while the inner horizontal portion posteriorly and horizontally to the lateral pole of the condyle and posterior part of the disc. The outer portion limits the extent of pure rotation while the inner portion resists posterior displacement of the condyle. The sphenomandibular ligament and stylomandibular ligament serve to resist excessive protrusive movements of the mandible[30].

1.6.2 - TMJ Dysfunction: Review of Literature

A) Classification

Two of the most common abnormalities of the TMJ are internal derangement and degenerative arthritis[31]. Although a close relationship can be established between these two processes[32,33], the precipitating condition is difficult to identify. Internal derangement is defined as an abnormal positional and functional relationship between the disc, the condyle, and the articulating surfaces of the temporal bone[34]. Osteoarthritis is a chronic condition resulting in joint deformity caused by degenerative changes in the articular cartilage, fibrous connective tissue, and disc within a joint. The initiating factors leading to the breakdown of the cartilage and tissue itself remains unknown, but the breakdown is accompanied by inflammation[35].

Disc displacements have been classified by the International Headache Society under disc derangement disorders[36] as disc displacement with reduction and disc displacement without reduction. If the disc is displaced anteriorly and snaps or clicks back into normal position when the mandible is opened, it is referred to as disc displacement with reduction. Clinically, this is associated with opening and closing clicking sounds or "reciprocal clicking". This clicking can be divided into early, intermediate or late, depending upon the distance from the fossa at which the disc assumes a normal relationship.

Disc displacement without reduction is where the disc remains anterior to the condyle regardless of jaw position. Clinically, this may be associated with painful limitation of jaw opening or a "closed lock". There may not be a limitation in the range of opening in some patients as there may be stretching or tearing of the posterior discal attachment[31]. The loss of the disc interposed between the condyle and the articular eminence results in a bone on bone condition with associated increase in stress on the incongruent articulating surfaces. This may lead to articular degeneration of the condyle and the articular tubercle[4,5,7,10,32,37-41]. Disc displacement with reduction may or may not progress to disc displacement without reduction. Lundh, Westesson and Kopp[42] followed 70 patients with reciprocal clicks for a period of three years. Clicking remained unchanged in 71 % of the patients and disappeared in 29 %.

The disc itself takes on new characteristics as a result of chronic displacement. The shape may change from biconcave to biconvex. There may be thinning, thickening or a change in length[23,24,43]. In those situations where the posterior discal attachment becomes interposed between the condyle and the posterior slope of the eminence, a conversion to fibrotic tissue has been observed suggesting a possible new load bearing function of this tissue[44].

These functional classifications of internal derangement are deceiving in that they imply that the disc is only displaced anteriorly. In general, the disc is displaced anteriorly or anteromedially[40]. Anatomically, the disc may occupy positions superior (normal), anterior, anteromedial, anterolateral, medial, and lateral[31]. Posterior displacement has been reported in the literature[45].

Osteoarthritis is commonly found in a variety of synovial joints throughout the body. It is defined as primary or secondary depending on the etiology[46]. It is categorized as primary depending on the absence of an identifiable or systemic etiologic factor. Primary osteoarthritis or degenerative joint disease (DJD) is defined as a degenerative condition of the joint characterized by deterioration or and abrasion of the articular tissue and associated remodeling of the underlying subchondral bone due to overload of the remodeling mechanism[35,47].

Secondary osteoarthritis involves the same process of breakdown with osseous remodeling as occurs in the primary condition with the main difference bring the association of a prior event or disease that overloaded the remodeling mechanism with secondary osteoarthritis. Potential etiologic factors include trauma, infection, history of active systemic arthritis, or internal derangement[48]. With internal derangement, there is some disagreement as to which is the precipitating condition. Stegenga et al.[49] have proposed that the osteoarthritic breakdown precedes internal derangement in most cases.

Research investigating the prevalence of osseous degeneration with internal derangement would suggest that displacement of the disc would precede the degenerative changes given the high prevalence of osteoarthritic changes in those with anterior disc displacement with reduction in comparison to control groups, and even higher occurrence in those with non-reducing and perforated discs[4,8,43,50]. This would support the concept that degenerative changes are sequelae of internal derangement rather than predecessors.

B) Prevalence

There is a significant amount of literature which describes the prevalence of TMD in the adult population. Solberg et al.[51] found an incidence of joint sounds of 28.3% in a sample of 369 men and 370 women non-patients with an average age of 22.5 years. Only 20.1% of the sample was completely free of any signs and symptoms of TMD. Dworkin et al.[52] reported 12.1% of their study population experienced TMD pain. In their non-pain sample, 25% experienced joint sounds while 33% of those with TMD pain had joint sounds. Agerberg and Bergenholtz[53] found TMJ sounds in 25% of their sample of Swedish men and women between the ages of 25 and 65, with a significantly higher prevalence among women and the elderly. Salonen et al.[54] had similar results in a study of 920 Swedish adult males and females. In addition, reported symptoms decreased with age while clinical signs of TMD increased. In agreement with this finding, Koidis et al.[55] found there was a relative decline by age in the severity of symptoms for women and for prevalence of symptoms for both genders in their sample of 148 women and 47 men between 16 and 70 years.

In summary, the adult population appears to have a high frequency of signs and symptoms of TMD. Joint sounds are found in approximately 25% of the population. Females have a higher prevalence of signs and symptoms than males. In a study of 197 consecutive orofacial pain patients, Bush et al.[56] attribute this to a greater health awareness of symptoms by women than men. Reported symptoms of TMD decrease with age while objective signs increase[57].

The profile of TMD in the adolescent population is slightly different than the adult population. Keeling et al.[58] examined 3428 Florida school children between the ages of 6 and 12 for signs of TMD. Joint sounds were found in 10% of the sample. Egermark-Eriksson[59] and his group of 402 Swedish children between the ages of 7 and 15 found that clinical signs of dysfunction ranged from 30% in the youngest group to 60% in the oldest, with the most common symptoms being TMJ sounds and tenderness of the muscles to palpation. There was a positive correlation between reported bruxism and clinical signs of dysfunction. Motegi et al.[60] examined 7337 Japanese children between the ages of 6 and 18 years of which 12.2% of the sample had at least one sign or symptom of TMD. The prevalence increased with age and was slightly higher in girls. Joint sounds were the most common symptom. In an older age group, Wanman and Agerberg[61] found the frequency of TMJ sounds to be 20% at the age of 18 in a sample of 258 subjects and were recorded more frequently in females than males. Approximately 50% of the sample had at least one sign of mandibular dysfunction . Similar results were reported by the same authors in a 2 year longitudinal study of 285 adolescents from 17 to 19 years of age[62]. Nilner and Lassing[63] found 36% of a sample of 440 Swedish children between the ages of 7 and 14 years reported symptoms of TMD. Joint clicking was reported in 13% of the sample. In a similar study on an older study population, Nilner[64] questioned a random sample of Swedish children between the ages of 15 and 18 years. TMD symptoms were reported in 41% of the sample and 17% indicated a history of clicking.

Thus, signs and symptoms of TMD are evident early in adolescence. The incidence of joint sounds is approximately 10-20% and the over all incidence of symptoms ranges from 30-60%. Females and older adolescents have a higher prevalence of signs and symptoms. Although the early detection of TMD is of value, signs and symptoms of TMD in children are a poor predictor for their occurrence in adulthood[65]. Magnusson et al.[65], in a 5-year longitudinal study of adolescents at the ages of 15 and 20 years, found no change in TMD signs and symptoms between examinations in nearly half the individuals, and impairment and improvement had occurred in the remaining half. For the entire study population, 31 % had joint sounds at the age of 15 and 34 % at the age of 20.

Although clinical and epidemiological studies into the prevalence of TMD in the adult and adolescent population may be of interest, diagnosis of internal derangement is only possible through imaging of the soft tissue of the temporomandibular joint with magnetic resonance imaging (MRI) or arthrography. Paesani et al.[66] reported the diagnostic accuracy of clinical examination alone to only be 43% in comparison to imaging findings with arthrography or MRI. Roberts et al.[67] had a clinical diagnostic accuracy of 59% in a similar study.

Katzberg et al.[68] examined the TMJ's of 76 asymptomatic volunteers and 102 symptomatic patients through MRI. Their findings indicated a prevalence of disc displacement in at least one joint in 33% of the asymptomatic sample and 77% of the symptomatic patients. Advanced stages of disc displacement were almost exclusively visualized in the symptomatic population.

Ishigaki et al.[69] arthrographically examined 360 temporomandibular joints in 247 patients with clinical signs and symptoms of TMD. Radiographic signs of internal derangement were found in 72.2% of the sample while 27.8% had radiographically normal joints. Of those with internal derangement, 47.3% had anterior disc displacement (ADD) with reduction, 32.3% had ADD without reduction, and 15.4 % ADD without reduction with perforation of the disc. Paesani et al.[70] had similar results in an arthrographic and MRI examination of 115 TMD patients.

Drace and Enzmann[71], in an MRI study of 50 asymptomatic temporomandibular joints, found 16 % had varied degrees of internal derangement. Westesson et al.[72] in an arthrographic examination of 40 clinically normal and asymptomatic joints, found 15 % of the sample had radiographic displacement of the disc. Kircos et al.[73] found an anterior disc position in 32% of 42 asymptomatic TMJ's visualized with MRI. It was suggested that these displaced discs did not cause any functional disturbance and were thus clinically silent. Thus, the presence of reported symptoms or clinical signs of internal derangement is not 100 % reliable in the diagnosis of internal derangement[37].

In summary, clinically silent joints may have radiographic signs of internal derangement but the prevalence of internal derangement appears to be much lower in the asymptomatic population[74]. In addition, a high percentage of TMD patients seeking treatment have radiographic evidence of internal derangement. As a result, these studies indicate that internal derangement is a significant factor to consider in the TMD patient.

C) Etiology

The potential combinations of potential predisposing, initiating, and perpetuating factors involved with the onset and progression of TMD is great. For this reason, consideration of the etiology of TMD will be broken up into a number of discrete factors which have been considered in the scientific literature. These factors are not mutually exclusive and may act in concert as precipitating or aggravating variables in the multifactorial etiology of TMD.

Trauma

Trauma to the temporomandibular joint can occur directly through a blow to the involved structures, indirectly via a blow but without contact to the involved structures, or through repetitive, cyclical adverse loading via parafunction. As for direct trauma to the structures of the temporomandibular joint, patients with TMD more often report having had physical trauma than non-patients. Pullinger and Seligman[75] found that the incidence of a previous traumatic event was significantly greater in a sample of 230 consecutively presenting TMD patients in comparison to a control group. Sullivan et al.[76] found disc displacement in ten of thirteeen patients who underwent MRI following acute condylar trauma, although the initial position of the disc prior to the traumatic event was unknown. Wilkes[77] found that less than 50% of patients can remember a history of injury associated with the onset of their condition. Of those who cannot remember a traumatic event, one must consider if they simply do not remember a previous injury that occurred during childhood or years prior to onset of the clinical manifestations of TMD.

Indirect trauma, with no direct blow to the face can cause symptoms consistent with TMD. There is evidence that TMD signs and symptoms are more common in those with a history of a whiplash type injury than in a non-injury controlled population[78,79]. Weinberg and Lapointe[80] have proposed that with cervical hyperextension as the initial phase of this injury, the posterior and polar discal attachments are stretched or torn. During the subsequent hyperflexion of the cervical structures, the head is propelled forward and the previously stretched discal attachments are crushed between the mandibular condyle and the glenoid fossa. This is one theoretical explanation, but a direct causal relationship between jaw symptoms and indirect trauma has yet to be established.

Repetitive adverse loading of the masticatory system has been hypothesized to occur through parafunctional habits. These habits include teeth clenching, tooth grinding, lip biting, and posturing of the mandible. Parafunctional habits have been suggested as initiating or perpetuating factors in certain subgroups of TMD patients. Solberg et al.[51] reported a prevalence of 7.9% in a sample of young adults. These habits have been most frequently assessed by indirect means such as presence of wear facets, soreness of jaw muscles upon wakening, sore teeth, reports by a bedroom partner, and nocturnal EMG monitoring[81]. Several authors have reported an association of bruxism with TMD, although this was assessed on the basis of patient history or the presence of occlusal wear facets[51,59,68,82].

Craniofacial Morphology

Research has suggested there is a causal relationship between internal derangement and abnormal growth of the facial skeleton[1,2,83,84]. According to Schellhas and coworkers[2], internal derangement leads to a deficient nutritional supply to the mandibular condyle, resulting in arrested growth. Dibbets and van der Weele[86], in a longitudinal study found that many of the facial characteristics found in adulthood precede the emergence of clinical TMD symptoms by at least 14 years. This finding suggests that not all TMD signs in adults can be implicated as being the result of some etiologic factor operating after adolescence. Finally, one must consider if the varied biomechanical loading of the condyle disc complex in certain facial patterns is the etiology of the disc displacement, rather than the ID causing altered growth[86,87].

In order to examine these issues, Schellhas and colleagues[82] retrospectively examined 100 orthognathic surgery patients with mandibular retrusion. Patients had undergone MRI to assess the status of the disc in each joint. Of the 100 patients, 88 were found to have internal derangement in at least one joint. The subjective degree of joint degeneration was correlated to the severity of mandibular retrognathia in most cases. Although the precipitating factor of mandibular retrusion or disc displacement is difficult to identify, the authors concluded that internal derangement leads to changes in facial morphology in a high percentage of cases. They speculated that this is due to a compromised blood supply to the mandibular condyle with resultant osteoarthritis, avascular necrosis, and osteoporosis. Similar conclusions were drawn from an adolescent sample[2].

Other studies have used disc position as a starting point and subsequently examined the associated facial morphology. Brand et al.[3] reported differences in skeletal patterns between 24 adult women with and 23 women without internal derangement confirmed by MRI. Cephalometric comparison of the two groups indicated that women with internal derangement had significantly shorter mandibles and maxillae in the horizontal dimension. Vertical relationships did not differ. Alternatively, Nebbe et al.[1] found that vertical relationships were altered with internal derangement in a pilot study of 25 preorthodontic adolescent patients. Specifically, internal derangement was associated with reduced ramus height, reduced posterior face height, and increased mandibular plane. In contrast to Brand et al.[3], Nebbe et al. found an increased degree of disc displacement was positively associated with an increased horizontal maxillary dimension. The underlying role of osteoarthritis in these cases must also be considered.

Occlusion and orthodontics

The contribution of occlusion to TMD and internal derangement has been assessed in the literature. In a review of literature, McNamara et al.[88] reported a relatively low association of occlusal factors in TMD. In this review, five occlusal features appear to be associated with various categories of TMD:

1. skeletal anterior open bite
2. overjets greater than 6 to 7 mm
3. CR/CO slides of greater than 4 mm
4. unilateral lingual crossbite

5. five or more missing posterior teeth.

The first three factors appear to be associated with TMJ arthropathy and may be sequelae rather than the etiology of changes in the temporomandibular joint. With the use of multiple regression, Pullinger et al.[89] found a relatively low association of occlusal factors in describing TMD. In general, there does not appear to be a strong relationship between internal derangement and occlusal factors.

With respect to the role of orthodontic treatment and TMD, Rendell et al.[90] examined 462 patients receiving orthodontic treatment in an orthodontic graduate clinic. Eleven of the patients presented with TMD prior to treatment. Using a dysfunction index, none of the patients who presented without signs or symptoms of TMD prior to treatment developed signs or symptoms during the 18 month investigation period. In addition, there was no significant change in the dysfunction experienced by those with signs and symptoms of TMD prior to treatment. These authors concluded that a relationship between TMD and orthodontic treatment could not be established. Other authors support the view of a lack of a significant relationship between orthodontic treatment and TMD[68,82,91-93].

Muscle Hyperactivity

Muscle hyperactivity has been proposed as a possible cause of internal derangement given that the lateral pterygoid may cause an anterior displacement of the disc with the attachment muscle fibers to the disc[94]. Alternatively, Juniper[95] has hypothesized that the activity of the lateral pterygoid is the result of anterior disc displacement rather than the cause. In an effort to resolve these two opposing views, Bittar et al.[28] examined the insertion of the lateral pterygoid in twenty TMJ's at autopsy. The average age of the autopsy specimens was 26.2 years. The lateral pterygoid showed no consistent divisions into separate anatomical heads at the insertion. The fibers inserted into the pterygoid fovea of the neck of the condyle in all cases. In 31 % of the cases, fibers were found to insert into the anterior portion of the disc. With only 2.4 % to 6 % of the total superior-inferior length of the muscle insertion inserting into the disc in those cases, it is suggested that the force generated by these fibers would be insufficient to initiate anterior disc displacement.

Osteoarthritis

There appears to be a cause and effect relationship between internal derangement and osteoarthitis, but which of these entities precedes the other has yet to be established. Brand et al.[4] found that 94% of cases with evidence of degenerative joint disease had arthrographic evidence of internal derangement while only 47% of the joints with internal derangement had evidence of DJD. Anderson and Katzberg[8] had similar findings in their tomographic and arthrographic study of 141 TMD patients. Of the patients with ADD with reduction, 9% showed signs of degeneration, but 39% and 60% of patients with nonreducing disc displacement and perforation respectively exhibited degenerative changes. In a 30 year follow up study of 55 TMJ's, De Leeuw et al.[33] found that those patients with reducing disc displacement showed less hard tissue structural change than those with a non-reducing disc. Based on the work of these authors, this would seem to show that degenerative changes are sequelae of internal derangement.

Moffet[15] has suggested that remodeling is induced by mechanical stimuli or altered nutritional status, but when the capacity of the joint for remodeling has been exceeded, remodeling merges gradually into osteoarthritis. When absolute or relative overloading of the joint occurs tissue breakdown may occur. Common radiographic changes include subchondral sclerosis, condylar flattening, osteophyte formation, lipping, erosions, or the formation of a cyst with the breakdown of subchondral bone[46]. This remodeling may also result in a shortening of the mandibular ramus vertical dimension. The distinction between osteoarthritis and physiological remodeling as an adaptive response is difficult radiographically, thus the difference between osteoarthritis and remodeling may only be distinguishable histologically on the basis of the integrity of the articular tissue[35]. Studies suggest that the soft tissue thickness in the components of the TMJ may compensate for bony irregularities that are radiographically observed[96-99]. In the event that the capacity of the soft tissue compensatory mechanisms are exceeded, exposure of bone may occur with subsequent perforation of the disc[100]. Changes in spatial relationships as well as condylar and temporal osseous morphology in relation to disc displacement will be described in following pages.

1.6.3 - Condylar position

A) Condylar position and internal derangement

Assessment of condylar position has been undertaken on the basis of the clinically based criteria for classification of joint status. Blaschke and Blaschke[101] determined the condyle-temporal bone spatial relationships in 50 clinically asymptomatic temporomandibular joints utilizing corrected lateral tomograms. The average condylar

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position for both the right and left joints was centered, but there was a large variability of individual positions around this mean. Dumas et al.[102] found that symptomatic condyles generally showed a more posterior position within the fossa than did asymptomatic condyles on lateral tomograms. His sample consisted of 28 females and 7 males with an average age of 40 years for the symptomatic groups and an unmatched control group of 3 females and 16 males with an average age of 26.5 years. Pullinger et al.[103] found that condyles were significantly more posterior in those with derangement than those that were asymptomatic in a tomographic study of 106 TMJ disorder patients. According to these findings, posterior condyle position may be considered a factor predisposing to internal derangement but the range of positions represented in clinically normal joints in these three studies would negate the use of radiographic condyle position as a primary means of diagnosis.

Definitive diagnosis of disc position is possible only with appropriate soft tissue imaging. Given the poor diagnostic accuracy of clinical examination with respect to disc position, clinically based studies on condylar position may not provide accurate information. Several researchers have used arthrography or MRI as a "gold standard" rather than clinical criteria for the examination of disc position. In a sample of 27 joints with arthrographic evidence of disc displacement without reduction and 13 joints with normal arthrograms, Katzberg did not find a significant difference between joints with documented internal derangement and those with normal disc position with respect to condylar position in the fossa.

Brand et al.[4], using subjective evaluation of condylar position on tomograms and arthrographic interpretation of disc position, found that condylar position was not significant in cases with anterior displacement of the disc in association with degenerative joint disease, but in the absence of tomographic evidence of DJD, a statistically significant 90% of the cases with anterior disc displacement without reduction revealed a retropositioning of the condyle in the tomograms. In the anterior disc displacement with reduction group, 88% were retropositioned. Of the cases with normal arthrograms 42% had posterior displacement of the condyle.

Kirk[5] examined condylar repositioning and joint space in axially corrected TMJ tomograms and correlated the findings with the MRI image of disc positioning in 35 joints. Joint space was measured from the superior surface of the condylar head to the edge of the glenoid fossa while other variables were subjectively assessed. The average measured superior joint space on tomographic examination was reduced with MRI evidence of disc displacement and dislocation. Of the joints with MRI evidence of disc displacement, 56% indicated a tendency for some condylar displacement from a centric position. His study suggested that there can be changes seen in axially corrected tomograms that may suggest the presence of disc displacement or significant internal derangement.

In a sample of 85 joints with disc displacement and 34 joints with normal disc position determined arthrographically, Ren et al.[6] found that the mean condylar position was significantly more posterior in lateral tomograms of joints with anterior disc displacement (ADD) with and without reduction. There was no significant difference for average condylar position between normal disk position and ADD with reduction alone. Despite these findings, the condyles in the normal group were essentially randomly distributed in anterior, concentric, and posterior positions in the glenoid fossa.

Approximately half of the joints with ADD with reduction and two-thirds of those with ADD without reduction appeared to have posterior condylar position. Similar to the studies based on clinical categorical data, the sensitivity and specificity of posterior condylar position with disc displacement was not great enough for it to be considered to be an adequate diagnostic test of disc position.

B) Condylar position and orthodontics

The possibility that orthodontic treatment influences condylar position has been hypothesized, but is not supported in the available literature. Artun et al.[105] examined condylar position in 29 females treated for Class II Div 1 with extraction of maxillary first premolars and 34 female patients treated for Angle Class I malocclusion without extractions. The authors attempted to test the hypothesis that retraction of the maxillary anterior teeth will produce a more posterior condylar position and wanted to evaluate the relationship between condylar position and signs and symptoms of internal derangement. Condyles were located significantly more posterior for the right condyle only when medial, central, and lateral slices were averaged in the extraction group. This difference was attributed to a high prevalence of anteriorly positioned condyles in the nonextraction group. Condyles were located further posteriorly in all three tomographic sections for patients with diagnosed or reported clicking in comparison to patients without clicking. There was no data on condylar position before treatment for the sample. In addition, tomographs were not corrected with the use of a SMV projection.

Gianelly et al.[106] found no difference in condylar position in corrected tomograms for 30 patients who had undergone four premolar extraction and a sample of 37 untreated patients. Furthermore, in a sample of 32 extraction and 79 nonextraction cases, Gianelly[107] found that condylar position is stable during treatment and does not behave differently under extraction and nonextraction conditions. No significant difference was found for condylar position in corrected tomograms between pre and post treatment records.

Recent data indicates that a small, but statistically significant increase in anterior joint space may occur with nonextraction fixed appliance treatment in direct comparison to extraction treatment[108]. The sample consisted of 22 extraction and 13 nonextraction cases. All cases were Class I skeletal and dental and had no signs or symptoms of TMD. Given that the increase in anterior joint space was only 0.39 to 0.49 mm, it is suggested that this change is clinically insignificant given the adaptive capability of the adolescent osseous and soft tissue.

The effect of crossbite and crossbite correction was examined by Hesse et al.[109] Pre and post-treatment tomograms of 22 patients treated for functional posterior crossbite between the ages of 4 and 12 years were evaluated. Results illustrated that the condyles on the non-crossbite side moved posterior and superior following crossbite correction. No differences were observed on the crossbite side. Relative condylar position was more anterior on the non-crossbite side before treatment, but similar on both sides after treatment.

C) Condylar position and malocclusion

Cohlmia et al.[11] identified a more anterior position of the condyle in the fossa of patients with Class III skeletal and dental relationships in a sample of 232 preorthodontic patients with varied malocclusions. Joint space measurements were made with the use of corrected tomograms. Patients with overjet measurements less than 1 mm had significantly larger linear measurements of anterior and posterior joint space as well as relatively more anteriorly positioned condyles. Seren et al.[110] evaluated axial CT sections of 21 untreated Class III skeletal adult patients in comparison to 18 adult patients with normal occlusions. Not unlike Cohlmia, they found a relative anterior condylar position correlated with skeletal Class III malocclusions.

Pullinger et al.[111] found that Class II malocclusions were associated with more nonconcentric condylar positions than Class I, with the position in Class II Division 1 being more frequently anterior as visualized on TMJ tomograms of 44 young adults. Condylar position had no relation to overbite. Similar results were found with respect to bite depth and condylar position in subsequent studies by Gianelly[106] and Gianelly et al.[112].

1.6.4 - The temporal component of the temporomandibular joint

An association has been made between osseous changes in the temporomandibular joint and internal derangement. The articular eminence plays an active role in this remodeling process. In a light microscopic examination of 22 joints, De Bont et al.[32] observed a flattening of articular eminence in subjects with anterior disc displacement. He also found that degenerative changes were found more frequently in the articular eminence than in the mandibular condyle and affected predominantly the lateral portion of the joint.

Kerstens et al.[38] found a steeper inclination of the posterior slope of the articular eminence in joints with anterior disc displacement as measured on panoramic radiographs. Among the joints with anterior disc displacement, there was no difference in the mean articular eminence angle for those with and without reduction. Of the patients grouped in the anterior disc displacement category, only 55 of 179 patients had MRI or arthrography to confirm the position of the disc while the remaining were placed in this category solely on the basis of clinical examination. The control group was made up of patients without clinical evidence of TMJ dysfunction but did not make use of imaging to confirm disc position. Thus, given the use of inappropriate imaging and data collection, the validity of this study must be questioned.

Galante et al.[113] found no significant differences in angular and linear measurements in the articular fossa of asymptomatic volunteers and symptomatic subjects with temporomandibular joint dysfunction on right and left full profile laminagraphs using MRI to categorize the disc status of the individual joints. The sample consisted of 74 symptomatic subjects with TMJ dysfunction, 29 asymptomatic volunteers with normal joints, and 6 asymptomatic volunteers with reductions made up the sample. The statistical power in this study may have been poor due to the overcategorization of data.

Panmekiate et al.[9] measured 20 joints from each of 3 groups with superior disc position, anterior disc displacement with reduction and anterior disc displacement without reduction. The diagnosis of joint status was made from arthrographic images. The joints were subject to tomographic evaluation to identify the characteristics of the slope of the articular eminence. Their results indicated that the posterior slope of the articular eminence is less prominent in those with anterior disc displacement without reduction than in normal and reducing joints. It was suggested that there is a progression from anterior disc displacement with reduction to anterior disc displacement without reduction to eventual osteoarthrosis. There was no difference in angulation between the three groups for angulation of the eminence. The lateral 1/3 of the joint was less steep than the central 1/3 in all three groups.

Ren et al.[10] found that the inclination of the articular eminence was steeper in 34 asymptomatic volunteers than in 71 patients with internal derangement as diagnosed with dual space arthrography. The inclination was a statistically significant 5 to 9 degrees flatter in the joints with evidence of internal derangement. Lateral sections were less steep than central and medial on average. Females had a non-significant 4-5 degree reduction in the angle of the eminence. The largest difference in the angle of the eminence was found between the persons with and without osseous changes. Thus, the findings of these studies implied that the steepness of the articular eminence is reduced in patients with anterior disc displacement and that these changes may occur with an increased frequency in the lateral component of the TMJ or the lateral component of the temporomandibular joint is anatomically flatter than the central and medial components[114].

In an effort to illustrate the effects of altered loading on the posterior slope of the articular eminence, Pirttiniemi et al.[115] experimentally moved the glenoid fossa posteriorly through fixation of the temporoparietal, interparietal, and lambdoidal sutures in rabbits. The eminence showed a shallower form in the experimental group. This was due to reduced proliferative activity on the posterior slope of the articular eminence and increases in proliferation anterior to the crest of the articular eminence as determined through histochemical analysis. The increased loading on the posterior slope is hypothesized to be the reason for the regressive remodeling while optimum load levels are produced near the crest of the eminence producing progressive remodeling. This finding can be explained by the load dependent growth curve for the development of the articular eminence[116,117]. The results of this study may help explain the flattening observed in the posterior slope of the articular eminence with altered functional loading conditions which occur with disc displacement.

Examination of the soft tissue of the articular eminence allows greater information to be gained than imaging alone. Bean, Omnell, and Oberg[118] found that macroscopic tissue changes in a sample of 20 temporomandibular joints obtained from autopsy specimens were most common in the lateral one-third of the joint in a lateromedial dimension for the temporal part of the joint. In an anteroposterior dimension, the temporal lesions were found predominantly in the eminence of the articular tubercle as well as in its posterior slope. In a similar study, Akerman, Kopp, and Rohlin[99] examined autopsy specimens ranging in age from 60 to 88 years and concluded that radiographic changes in the temporal component most often had intact soft tissue macroscopically. This would contrast with radiologic erosions in the condyle which were associated with macroscopic lesions.

The influence of the articular eminence on the development of the face and malocclusion is not well known. Seren et al.[110] found a relatively smaller glenoid fossa in Class III adults in relation to a Class I control group. Cohlmia et al.[11] found a significantly shallower articular slope angle in open bite subjects than normal or deep bite subjects. In addition, patients with steep mandibular planes had a significantly smaller fossa depth and angle to the articular slope. Subjects with an overjet of less than 1 mm had significantly smaller mean fossa depth. Solberg et al.[119] found a statistically significant increase for deviations in form of the eminence in autopsy specimens with anterior crossbite. These finding may be attributed to altered loading patterns due to the lack of anterior guidance in these patients or an anterior disc position with subsequent remodeling. With the limited existing research in this area, further investigation is warranted.

1.6.5 - Condylar morphology

A) Condylar morphology and internal derangement

The relationship between condylar deformity and disc displacement has been defined. In general, there appears to be a significant correlation between the severity of internal derangement and condylar bony remodeling. Kirk[5], in a sample of 35 joints, found that joints with MRI evidence of total disc dislocation showed bony evidence of degenerative changes in tomographic images. Conversely, joints with superior disc position or with ADD with reduction had no osseous changes suggestive of degenerative joint disease. This suggested that there may be changes in axially corrected tomograms suggestive of internal derangement.

Brooks et al.[39], in support of Kirk's findings, found 35 % of a sample 34 joints with no radiographic soft tissue or clinical signs of internal derangement had minimal flattening of the condyle or articular tubercle in sagitally corrected tomograms. The authors conclude that minimal flattening is probably of no clinical significance and that generally no osseous changes occur in the TMJ of asymptomatic persons without internal derangement. The majority of osseous changes appear to be associated with late-stage internal derangement.

The presence of subjectively evaluated osseous changes were found to be significantly greater in patients with ADD without reduction (43.8%) than with reduction (10.8%) by Ren et al.[6]. The sample consisted of 34 patients with normal disc position and 71 symptomatic patients with internal derangement. Osseous changes consisted of sclerosis, erosion, or osteophyte formation on the condyle

With magnetic resonance imaging, Rao et al.[7] examined 276 TM joints in 138 symptomatic patients for changes in shape and size in order to correlate their findings with internal derangement. The condyle was abnormal in 98 of the 276 joints. Of the 98 joints with abnormal condyles, 94 had internal derangement. Of the 181 joints with ID, condylar morphology was normal in 50% and altered in 50%. Bony changes were seen in 65% of joints with anterior disc displacement without reduction and 45% of joints with anterior disc displacement with reduction. Thus, there appears to be a significant correlation between the severity of ID and regressive condylar bony remodeling.

Brand et al.[4] found that 94% of cases with DJD had arthrographic evidence of internal derangement, whereas only 47% of the cases with internal derangement had evidence of DJD. Perforations were seen in 27% of cases with DJD and in none of the cases without DJD.

Anderson and Katzberg[8] compared arthrographic and tomographic findings in a sample of 141 patients with TMJ symptoms of an average age of 26 years. Their objective was to assess the incidence and severity of associated osseous abnormalities (erosions, flattening of eminence or condyle, osteophyte formation) associated with internal derangement. Twenty eight percent of the joints had significant osseous abnormalities compatible with DJD. The incidence and severity of the degenerative changes compared favorably with the arthrographic assessment of the degree of soft-tissue injury. The authors suggest that soft tissue abnormalities precede the osseous changes and early intervention in the prevention of osseous degeneration.

De Bont et al.[32] in a study of 22 randomly selected autopsy specimens attempted to describe the osteoarthritic changes associated with internal derangement. Light microscopic degenerative changes were found in 11 of 14 joints with internal derangement and in 4 of 8 joints with normal disc position. Internal derangement appeared to be associated with osteoarthritis.

B) Condylar morphology, occlusion, and orthodontics

Condylar characteristics such as size, shape, and surface configuration have been investigated in imaging and autopsy studies in relation to malocclusion. The purpose is to classify certain types of malocclusion with changes in condylar shape with the assumption that malocclusion plays an active role in temporomandibular disorders. Crossbite has been implicated as having a significant effect on the shape and size of the condyle[119]. Tadej et al.[12] used SMV's and tomographic images to examine 44 male and 60 female pre-orthodontic patients with an average age of 15.7 months. Medio-lateral condylar width had a significantly slower increase in patients with a midline shift, but the antero-posterior dimension was unaffected. Cohlmia et al.[11] found that patients without crossbite had significantly larger condylar heads than those with crossbite in the A-P dimension. These authors did not differentiate between anterior or posterior crossbite in their classification of malocclusion.

When anteroposterior dental and skeletal relations are examined, the findings are somewhat more ambiguous. Seren et al.[110] found increased mediolateral dimensions to the condyle in a sample of Class III adults. Solberg et al.[119], in a sample of 96 joints taken from autopsy specimens, found that Class II and III dentitions were associated with deviations in form of the condyle and articular eminence more than Class I dentitions. Class II dentitions were accompanied by greater histologic evidence of remodeling changes in the TMJ's. Deep overbite was associated with flat condyles whereas abnormal overjet was evident in those with histologic evidence of arthrosis in all joint components.

Occlusal function may play a role in the anatomy of the condylar head. Hinton[120] measured the TMJ's of human skulls from a broad range of subsistence practices with the use of samples dated from 800 AD to the 20th century in an attempt to correlate orofacial function with TMJ size. The findings indicate that there is a significant difference in size among the mandibular joints of recent and aboriginal human groups. Furthermore, the differences are highly patterned among hunterers and gatherers, agriculturalists, and industrialized groups. Although there may be a strong genetic role to this pattern, these findings support the hypothesis that orofacial function may account for the size differences in the joint.

Mongini[121] examined 100 crania which ranged from 18 to 67 years at death and attempted to relate the condition of the dental arches to the morphology of the mandibular condyle. He examined 3 slices from each condyle which were 1 mm thick from medial to lateral. The sites of remodeling were evaluated and related to age and partial edentulism.

He found that remodeling is most frequent on the anterior and posterior surfaces of the condyle. The incidence of remodeling increased rapidly between the ages of 18 and 25 after which age had no significant influence, and remodeling became more frequent as the number of missing teeth increased. In a similar study, Mongini[122] examined the factor of dental abrasion in 100 skulls with complete dental arches aged between 20 and 53 years at the time of death. He found that dental abrasion and the shape of the condyle did possess a degree of correlation although the variability in the data was high.

Investigation of condylar morphology in relation to orthodontic treatment was undertaken by Peltola[123] who found an increased prevalence of condylar changes in the posttreatment panoramatomograms of 235 orthodontically treated students between the age of 19 and 25 in comparison to 733 untreated students. Flattening and subcortical sclerosis were the most common variations in the treated group. It cannot be concluded if it was orthodontic treatment, disc status, malocclusion, or skeletal dysplasia that led to the difference in the two groups.

C) - Condylar morphology and growth

Growth in the size of the joint appears to cease by late teens or early twenties[124,125]. The question as to whether or not the condyle will respond to changes in environment secondary to orthodontic treatment, seasonal growth, and internal derangement during this period of development has been investigated. McNamara and Carlson[126] examined the adaptation of the TMJ to protrusive function in rhesus monkeys. Ticonium inlays were cemented in 14 rhesus monkeys to posture the mandible down 3 mm and forward 4 mm. Animals were sacrificed at various time intervals and compared to controls histologically. An adaptive increase of the condylar soft tissue posteriorly and postero-superiorly was evident within 2 weeks and continued on until the sixth week mark where it began to decline to control levels over the remainder of the study. From this, one can hypothesize that the cartilage of the mandibular condyle is highly responsive to changes in the biomechanical and biophysical environment of the temporomandibular joint region during growth.

Dibbets and van der Weele[127] presented the hypothesis that there is seasonal variation in the growth of the condyle and that the radiographic appearance of the condyle may be a reflection of this growth. This hypothesis is based upon the variation seen in adolescent TMJ radiographs during the Groningen Longitudinal Cranio Mandibular Dysfunction Study and the circannual rhythm observed in the mitoses of cells in the condyles of rats[128]. Using a cross-sectional approach, the bi-monthly percentage of flattened projections in 161 pre-orthodontic patients without evidence of TMD and an average age of 12.5 years were calculated. The results indicate that the flattened appearance of children's condyles exhibit a seasonal variation, with a growth acceleration in the spring and summer, declining to a minimum in the fall.

Schellhas et al.[2] retrospectively evaluated 128 children who had undergone both radiographic and MR imaging of both temporomandibular joints for suspected internal derangement. Through radiographic interpretation of the images and staging of the derangement, the data presented suggests a high clinical prevalence and structural significance of TMJ derangements in pediatric dysmorphology populations. The authors suggested that internal derangements of the TMJ disc either retards or arrests condylar growth, which results in reduced vertical dimension in the proximal mandibular segments with subsequent mandibular deficiency or asymmetry.

1.6.6 - Soft Tissues of the Temporomandibular Joint

Hansson et al.[97] examined the soft tissue architecture in 48 joints without any signs of arthrosis or deviation in form histologically to establish a baseline of normal. The tissue was thickest on the antero-superior surface of the condyle (0.4-0.5 mm), the postero-inferior slope of the articular tubercle (0.5 mm) and the posterior band of the disc (2.9 mm). The layers were thinner laterally on the condyle, but thicker laterally on the temporal component. The thickness of these layers may reflect the greater functional loads to which these areas must withstand during function in the adult, and the role that these areas play in growth in the adolescent. From the same sample of autopsy specimens, Hansson and Nordstrom[129] examined 22 more joints with evidence of deviation in form for the same soft tissue thickness measurements. In comparison to the healthy joints, the soft tissue layers were in general thicker, but only significantly for the posterior and superior portion of the lateral part of the condyle and in the temporal component, the anterior slope of the tubercle and the roof of the fossa. These increased soft tissue layers are attributed to the biomechanical stimulation of undifferentiated mesenchyme which increases the soft tissue thickness in areas of increased loading.

Autopsy studies impart valuable information regarding the articular tissues of the condyle and temporomandibular joint that are not obtainable through imaging studies. Bean, Omnell, and Oberg[118] evaluated macroscopic tissue changes in 20 temporomandibular joints obtained from autopsy specimens ranging with an average age of 72.8 years in order to compare the macroscopic appearance of the articular tissues with radiological observations. For hard tissue changes, the condyle showed relatively equal incidence of changes in the lateral, central, and medial one-third of the condyle. In the anteroposterior dimension, macroscopic hard tissue lesions were most common in the superior part of the condyle. For the temporal component of the joint, the occurrence of lesions was more frequent in the lateral and central one-third of the joint and occurred primarily at the crest of the eminence and the posterior slope. Almost all of the arthritic lesions in the soft tissue were associated with destruction of the subarticular compact bone, but in several situations, there was an intact articular surface with extensive degeneration of the subarticular bone. Their findings agree with Hansson and Oberg[96] in that arthritic lesions were mainly localized in the temporal component of the lateral aspect of the TMJ. As a point of interest, all 13 of the joints in Hansson and Oberg's autopsy study that were under 20 years of age revealed smooth and unaffected surfaces of the condyle and eminence, with no evidence of arthrosis. No indication of disc position was given in this autopsy study. The implication of these studies would be that osteoarthrosis does not appear to be the main pathologic feature underlying TMJ symptoms in young adults[40,100]. Secondly, in support of the findings in imaging studies, remodeling and osteoarthritic changes occur predominantly in the lateral part of the joint [32, 96, 118].

Examination of the soft tissues of the temporomandibular joint can also provide data on growth and maturation. Based on a small sample of 11 male and 10 female joints ranging in age from 18 to 36 years, Lubsen et al.[98] histologically examined the changes in cartilage and subchondral bone that occur with aging. He found that there were no significant differences between male and female mature condyles, but did find that males retained their "immature" status until a greater age. The immature condyle would be characterized by greater soft tissue thickness, reduced bone thickness and amount, and greater vascular spaces. With the associated increase in soft tissue thickness, the greater cellularity may allow for greater growth and adaptive potential later in adolescence for the male.

Radiographic imaging may not provide an accurate description of the changes occurring in the TMJ. Flygare et al.[130] examined 40 TMJ's taken from autopsy specimens with an average age of 75 years. No indication of disc position was given. Tomographic images of the specimens were taken to examine the radiographic appearance of erosions and were then verified by microscopic and macroscopic examination. In contrast to Bean, Omnell and Oberg[118], these investigators found that the frequency of severe erosive changes occurred with similar frequency in the temporal component and the condyle of the TMJ. For the temporal component, there was a higher incidence of false positive radiologic diagnosis as hard tissue changes were masked macroscopically by the presence of an intact articular surface, similar to the findings of the earlier research[32,118]. Therefore, radiographic description of osseous changes should be interpreted with caution.

Pullinger et al.[18] examined soft tissue thickness of the articular eminence in autopsy specimens. In their first study, the osseous architecture of central sagittal histologic sections of the temporal component of 51 temporomandibular joints of young adults at autopsy were used to determine if osseous contours predicted the thickness of the overlying soft tissue and disc displacement. There was a weak correlation between increased soft tissue thickness and a flat articular slope, perhaps compensating for osseous remodeling or having a delayed type remodeling. In their second paper, Pullinger et al.[131] examined variables of sex, age, eminence curvature, eminence length and slope and found that none of these variables are useful predictors of the overlying articular soft tissue pattern. Thus, if the overlying soft tissue pattern cannot be predicted from the osseous contours or other variables, the interpretation of the morphology of the joint is suspect with hard tissue imaging. This finding may also have implications in the interpretation of joint space if one is to consider a potential 1.5 mm of soft tissue at the articular eminence in addition to a potential 1.0 mm on the condylar head.

1.6.7 - Loading of the temporomandibular joint

Indirect mathematically based biomechanical [132-135] and finite element analysis models [86,136-140] of the mandible during function as well as direct measurement [141,142], provide evidence that the mandible is loaded during function. Calculation of the joint reaction force requires three sets of information[143]: the magnitude and direction of the bite force, the magnitude and directions of each muscle force, and the lengths of the moment arms of the bite and muscle forces. Because of measurement error, individual variability, and an inability to predict all of these variables, the directions and magnitudes of force on the condyles under all conditions of normal function are unknown.

For force magnitude, Faulkner et al.[144] has shown that the TMJ is load bearing and that the balancing side condyle is more heavily loaded during unilateral biting, taking approximately two-thirds of the total condylar load regardless of occlusal position. In addition, these biomechanical models predict that the force magnitude of condylar forces is increased as the point of application of bite force is moved anteriorly[134,135,141]. Smith et al.[135] found a maximum appositional force of 60% of bite force when applied at the incisors and a distracting force of about 5% when applied to the distal surfaces of the third molars. Overall, TMJ loads tended to reach a minimum as a result of vertically directed bite forces positioned at the second molars, and a maximum in response to mediolaterally directed bite forces.

The actual force magnitude is only one component of the equation when one considers the distribution of load in the temporomandibular joint. In any joint, the stress, or force per unit area must be considered. This can be expressed as congruity because as the congruity of surfaces decrease, pressure gradients increase[145]. In an effort to investigate this phenomenon in growing temporomandibular joints, Nickel et al.[146], examined the congruency of the loading surfaces of the temporomandibular joint. Based on 52 osteological specimens ranging between birth and 25 years, the authors examined the congruency of the TMJ with the condyle centered and with the condyle in incisal biting. The results indicate that there is a greater reduction in congruency in the protrusive biting positions and where there is an increase in the steepness of the eminence.

Another variable that must be considered with respect to force magnitude and distribution of condylar load is that of the disc. The TMJ disc has been said to distribute condylar reaction forces over an area of 1 cm squared[134]. Nickel and Mclachlan[145], in an *in vitro* study of the pig disc, found that the disc reduces condylar load by about half and that disc thickness was a critical factor in determining the peak stresses measured under the disc. This is primarily due to the differing elastic moduli of the disc and bone[147].

Finally, the biomechanical models tend to ignore the error that may occur in muscle force calculation, generally based on average EMG values[148], cadaver muscle cross section [86,149], or both [133,134,150]. In reality, the actual muscle forces can only result from a complex interaction of true muscle weight, cross-sectional area, actin/myosin ratios, vascularization, innervation, and peculiarities of muscle architecture[86]. In addition, the role of muscular inhibition must be considered[134,144,151,152].

Determination of the joint reaction vector is an important indicator of where on the condyle or fossa the signs of excessive loads would first appear. Biomechanical models predict that joint reaction forces are essentially perpendicular to the articular eminence in order to maintain equilibrium in the models[134,136,144,150]. With respect to the range of direction, Smith et al.[135] found that bite force without a lateral component acted through an angle of 25 degrees. Tanaka et al.[149] in a three dimensional finite element model of the TMJ, examined the stress distributions in the TMJ during centric clenching. In the anteroposterior dimension, compressive stresses were induced in the anterior and superior areas with tensile areas posteriorly. Mediolaterally, compressive stresses were generated laterally and tensile medially.

When a lateral component to the bite force is introduced, the profile of joint loading changes. Faulkner et al.[144] found that balancing side (contralateral) loading angles were measured approximately perpendicular to the posterior slope of the articular eminence and acted through a range of approximately 15 degrees. For the working side (ipsilateral), reaction force direction varied considerably and acted through an angle of 90 to 120 degrees when occlusal load applied at the first and second molar respectively. This suggests that the ipsilateral condyle is positioned centrally in the fossa and that it acts as a stabilizing pivot which is lightly loaded. Based upon a slightly different model, Smith et al.[135] found that when lateral components were introduced into the bite forces, the ipsilateral temporomandibular joint was loaded through an angle of 65 degrees. The contralateral condyle was subjected to the same range of forces plus a tendency to move inferiorly or inferomedially.

The determination of joint force direction is most sensitive to error in the determination of muscle force direction[143]. Among the methods used to determine muscle force direction have been:

1. Using a line between the centers of origins and insertion of muscles[133-135,149,150].
2. Use of prominent landmarks in lateral cephalograms[85].
3. Anatomical dissection[85,132].

Despite these attempts, Goto et al.[153] have argued that the direction of the jaw muscle forces along with there insertion is continuously changing during normal function and that assigning a single, constant direction for each of the jaw muscle forces is unlikely to be possible without direct measurement of the motion of visualized muscle parts. Based on this, biomechanical models based on static force analysis may be only apply during isometric clenching.

1.6.8 - TMJ tomography

Tomography is a radiographic technique that relies on blurring the images of structures superficial and deep to the focal plane. For the temporomandibular joint, images of the joint are made through the joint at varied thicknesses and distances. The best definition of an image occurs when the anatomy to be blurred is approached from several different directions, and therefore a hypocycloidal tube motion produces the best definition. When tomographic images are axially corrected to the mediolateral long axis of the TMJ, reliable information about the structure, morphology, and spatial relationships of the osseous components of the TMJ's can be produced[154].

1.6.9 - Analyses and reference systems

A) Condylar position and joint space

For joint space and condylar position in tomographic images, Cederberg[155] has shown that anatomic osseous and radiographic images of joint space are closely related on a dry skull. Although this imaging technique can detect the gross osseous features and changes within the joint, it is unable to image the articular disc, articular soft tissues or disc attachments[156]. The soft tissues covering the condyle and temporal component of the TMJ have been measured from direct specimens and thickness has been shown to vary depending on location in the joint and position of the disc in the fossa[18,96,97,129,131]. In addition, the role of mandibular posturing and remodeling secondary to primary or secondary osteoarthritis must be considered when assessing joint space and condylar position[154]. Thus, it cannot be used to confirm disc position when internal derangement is suspected. Despite this, many clinicians routinely assess joint space and condylar position within the fossa with the expectation that these findings may provide clues to whether or not there is internal derangement.

A variety of methods for the assessment of condylar position have been proposed in the literature. These reference systems have utilized subjective assessment[39,157], linear measurements[5,11,102, 158,159], area calculation[160,104], projective geometry[161], and three dimensional construction of the condyle and the glenoid fossa[162] relative to anatomic or constructed reference points. In addition, these measurements have been expressed as absolute values as well as proportionally to compensate for individual variability in the anatomic components of the temporomandibular joint.

A comparison of two linear and two area measurement systems utilized to relate the position of the condyle within the fossa were compared by Karpac et al.[163] to determine if there was a statistically significant difference among the four different systems. One hundred TM joints from 50 dry skulls were assessed on axially corrected tomograms. There was no significant difference between the four techniques analyzed.

Pullinger and Hollender[159] examined six reference systems used for the evaluation of condyle fossa relationships. The use of area analysis with the midpoint of the fossa reduced the number of nonconcentric positions relative to other systems. Area analysis at the midpoint condyle position tended to increase the number of nonconcentric positions. Linear measurement of the subjective closest posterior and anterior interarticular space, expressed as either a logarithmic ratio or a difference relative to the available joint space was considered to be the method of choice due to low interobserver variability and the functional relevance to the thickness of the center of the articular disc.

Variation in patient positioning has been shown to have a potential significant effect on linear and angular measurements in TMJ tomograms[164]. To examine this issue with respect to Frankfort Horizontal and joint space, Kamelchuk et al.[165] examined the Dumas method[102] of joint space analysis to determine the affect of head rotation on joint space measurements. Sixteen female joints were imaged using axially corrected tomography and the resultant radiographs were traced and measured. Simulated head rotations of +/- 10 degrees in the sagittal plane were applied to the tracings and the measurement process was repeated for the sample. Their findings indicate that there is no significant difference for joint space measurements with +/- 10 degrees of rotation about the reference plane.

B) Temporal component of the temporomandibular joint

The quantification of the characteristics of the components of the articular eminence in imaging has not produced a tremendous amount of variety in terms of methodology within the literature. The angle of the articular slope of the eminence relative to Frankfort Horizontal is the primary focus of numerous investigations[6,11,113]. Fossa depth has been measured from the height of the glenoid fossa, perpendicular to Frankfort Horizontal[11,102,113]. Subjective evaluation of the radiographic and morphologic characteristics of the eminence has also been employed[114,157]. Panmekiate et al.[9] measured the angle of the slope relative to FH as well as the prominence of the slope as a linear distance from the midpoint of the fossa to the posterior slope of the articular eminence. Gynther et al.[157] suggested the identification of subjective changes in at least two tomographic cuts to avoid misinterpretation.

C) Condylar morphology

Although tomography is inappropriate as a diagnostic test for TMJ internal derangement[166], several authors have demonstrated the validity of tomography for assessment of osseous contours. Watt-Smith et al.[167] found that tomograms were the best indicators of osseous abnormalities. Greenwood[168] and others[118,130,169] found tomography had a high degree of correlation with bony pathology.

The primary obstacle in defining condylar morphology is the quantification of the dimensions for the purpose of between patient comparison and establishment of an anatomically valid reference system. As with the assessment of condylar position, the assumption that stable anatomic landmarks are available or the extrapolation of assumed reference planes is difficult to defend. Linear measurement of the A-P thickness of the condyle[11,12] has been evaluated in sagittal tomograms using a variety of arbitrary landmarks. This may explain why subjective evaluation of changes in condylar radiographic characteristics and size has been the primary mode of analysis[13,14].

In summary, there is a deficiency in the literature for the quantification of condylar and temporal osseous contours in relation to internal derangement, growth, or malocclusion. The establishment of a valid reference system would remove the subjective nature of this measure given the considerable variability and lack of standardization which makes comparison between studies awkward. Unfortunately, it is difficult to describe a single anatomical landmark that is not subject to remodeling in the dynamic temporomandibular joint which necessitates the exploration of alternative modes of reference.

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Chapter Two

Research Paper #1

Osseous Morphology and Spatial Relationships of the Temporomandibular Joint: Comparison Between Normal and Anterior Disc Position

2.1 - Introduction

Several investigators have suggested that condylar position is related to internal derangements of the temporomandibular joint (TMJ). With respect to joint space analysis and the use of condylar position as a diagnostic tool, studies suggest that there are statistically significant differences in condylar position and absolute value of joint space between those with altered disc position, verified with arthrography or magnetic resonance imaging (MRI), and those with normal disc position[1-3]. Despite these findings, radiographically determined condylar retrusion or non-concentric joint space does not necessarily predict internal derangement (ID). Research has suggested that measurement of joint space and determination of condylar position is of questionable value given the high variability of condylar position within the fossa in the adult population[3-6]. Although the variability of condylar position in the adult population may minimize the diagnostic value of the measurement, there may be value in the assessment of joint space and condylar position in an adolescent study group. There is a deficiency in the literature with respect to the assessment of joint space in an adolescent age group in relation to the position of the disc in the joint. This data may provide information on normal anatomy of the developing TMJ, how the joint space in adolescents with normal and altered disc position compares to their adult counterparts, provide other investigators a baseline of normal and give clues to differences in the development of the TMJ's of those with and without derangement.

Research often postulates that a cause and effect relationship exists between ID and osteoarthritis, but which of these entities precedes the other is yet to be established. Brand et al.[1] found that 94% of cases with evidence of degenerative joint disease had arthrographic evidence of ID while only 47% of the joints with ID had evidence of DJD. Anderson and Katzberg[7] had similar findings in their tomographic and arthrographic study of 141 TMD patients. Of the patients with disc displacement with reduction, 9% showed signs of degeneration, but 39% and 60% of patients with non-reducing disc displacement and perforation respectively exhibited degenerative changes. De Leeuw et al.[8] found that those patients with reducing disc displacement showed less hard tissue structural change than those with non-reducing disc in a 30 year follow up study of 55 joints. These authors support the observation that degenerative changes are secondary to ID in most cases.

Displacement of the disc would necessitate alteration of loading conditions and the nutritional status in the TMJ[9,10]. The altered joint dynamics and increased shearing stresses associated with internal derangement may lead to physiologic remodeling in an effort to increase the congruity of the loading surfaces of the joint and reduce the force per unit area[11]. When the capacity of the joint for remodeling has been exceeded, with or without disc displacement, remodeling may progress gradually into osteoarthritis[12]. Common radiographic changes include subchondral sclerosis, flattening of the condyle and articular eminence, osteophyte formation, lipping, erosions, or the formation of a cyst with the breakdown of subchondral bone[13]. The distinction between osteoarthritis and physiological remodeling as an adaptive response is difficult radiographically and may only be distinguishable histologically on the basis of the articular tissue integrity or synovial fluid markers[14-16]. Objective examination of radiologic osseous contours may provide clues as to the distinction between physiologic remodeling and osteoarthritic changes.

Although tomography is inappropriate as a diagnostic test for ID[17], several authors have demonstrated the validity of tomography for assessment of osseous contours and abnormalities[18-22]. The primary obstacle is defining a valid reference paradigm for condylar and eminence morphology to enable quantification between patients. Linear and angular measurements relative to constructed or arbitrary reference points[23-26] as well as subjective evaluation of changes in the condylar and temporal components have all been examined in radiographic images of the temporomandibular joints.

The purpose of this retrospective research study was to objectively determine if temporomandibular disc position is associated with specific positional and morphological changes of the osseous components of the TMJ, as viewed in an axially corrected tomographs of an adolescent population. By examining this relationship, the contribution of tomographic radiographs in the identification of joint abnormalities in an adolescent population can be assessed. In addition, information derived from this study may lead to an increased understanding of some of the contributing factors and sequelae to ID in an adolescent population.

2.2 - Materials and Methods

Axially corrected tomographic radiographs and MRI of 335 TMJ's in 175 subjects (106 female and 69 male) between the ages of 7.27 - 20.0 years (mean age 13.08 yrs) were used for this study. Mean male age was 13.02 years and mean female age was 13.12 years. Subjects consisted of individuals who presented sequentially to a private imaging facility for orthodontic records, regardless of TMJ status, and from whom consent was obtained for participation in the study.

I. Tomographic Technique

All tomographic images were exposed at the same private imaging facility using a Tomax Ultra-scan (Incubation Industries, Inc., 429 Easton Road, Warrington, PA, 18976) with hypocycloidal motion. Exposure settings were at 100 milliseconds, 5 mA and 78 kVp. Head positioning was established by alignment of Frankfort plane parallel to the plane of the film with the teeth in maximum intercuspation making use of a polyvinylsiloxane (President Jet - Bite, Coltene / Whaledent Inc., Mahwah, New Jersey) centric occlusion bite registration.

All tomographic radiographs were viewed under standardized conditions and traced onto acetate overlays using a 0.3 mm diameter lead pencil. Each tomographic radiograph was traced approximately one week apart by the principal investigator and involved the identification of the outline of the mandibular condyle and glenoid fossa. The central slice of the tomographic survey was used for this study. Each tracing was scanned at 600 dpi by the same investigator using a UMAX 1200S scanner (Taiwan). A computer program was written in Microsoft Visual Basic for Windows (Microsoft Corporation, Washington, DC) which interpreted data entered and returned angular, curvature, and distance measurements. The curvature calculation was validated through the repeated measurement of known polynomial curves at known locations. The average curvature calculation was verified by repeated measurements of varying radii. For both measures the calculated variance was less than 1% of actual values.

II. MRI data

MRI of the TMJ's were performed without sedation using a 1.0 T magnet (Shimadzu Corporation 3, Kanda-Nishikicho 1-chrome, Chiyoda-Ku, Tokoyo 101, Japan) and a unilateral 3 inch surface receiver coil. Axial scout images were obtained to identify the condyles. Bilateral closed mouth sagittal sections were obtained perpendicular to the long axis of the condyle making use of the same polyvinylsiloxane centric occlusion bite registration utilized in the tomographic survey. T1 - weighted 500/20 (TR ms/TE ms) pulse sequences were performed on all subjects using a 3 mm slice thickness, 140 mm field of view, NEX of 2, and an image matrix of 204 x 204.

The most representative central sagittal slice of the joint was subjectively evaluated by an experienced radiologist to determine disc position. Of the joints evaluated, only those joints which exhibited normal disc position and those with full displacement of the articular disc were evaluated in this study. Normal disc position was defined as where in the closed mouth position the intermediate zone of the disc was interposed between the head of the condyle and the posterior slope of the articular eminence, with the anterior and posterior bands equally spaced on either side of the condylar load point in a bow tie appearance. Full displacement of the articular disc was defined as when the articular disc was anteriorly displaced relative to the posterior slope of the articular eminence and the head of the condyle. The bilaminar zone of the disc was interposed between the osseous articular structures and occupied the narrowest joint space. Disc reduction, non-reduction, or perforation were not criteria for assessment in this classification scheme.

III. Determination of Loading Distance

Determination of the loading surfaces of the condyle and the posterior slope of the articular eminence was based on the biomechanical model of Smith et al[27]. It was assumed that condylar reaction forces during maximum intercuspation were directed essentially perpendicular to the posterior slope of the articular eminence[27-31] and that the condylar loading point corresponded with the closest joint space perpendicular to the posterior slope of the articular eminence[30]. Except in few joints with extensive condylar and posterior slope flattening, the visual identification of anterior joint space was straightforward. In those problem cases, the center point of the flat region was used.

Condylar reaction forces were assumed to act through an angle of 32.5 degrees superior and 32.5 degrees inferior perpendicular to the posterior slope of the articular eminence through the condylar loading point during unilateral biting[27]. In order to develop a loading distance for the purposes of this study, 10 female and 10 male joints representative of normal disc position and, 10 female and 9 male joints representative of disc displacement were randomly selected. Only TMJ's from separate patients were considered. The closest anterior joint space was measured perpendicular to the posterior slope of the articular eminence. The posterior slope of the articular eminence was identified by two circles with closest fit to the glenoid fossa and the articular tubercle, respectively. The inflection of the posterior slope of the eminence from the circle circumferences provided two points to include a single tangent to the circles, which was parallel to the articular eminence (Fig 2-1)[32].

The error of measurement was determined by selecting 10 tomographic images representative of normal disc position and 10 representative of disc displacement. These twenty tomographic images were traced five times, scanned at 600 dpi, and the closest anterior joint space was measured twice on each image. The standard deviation of the linear measure was determined over the five tracings of each radiograph. Subsequently, the average SD for each angular and linear measure was determined by calculating the average SD value over all twenty radiographs (Table 2-1).

Independent t-tests comparing gender in the normal and abnormal groups indicated no significant differences with respect to anterior joint space ($p>.05$). Since the anterior joint space for the abnormal group was significantly greater than for the normal group ($p<.05$), the abnormal group was used for the determination of the loading distance. Three male and seventeen female TMJ's with anterior disc position were randomly selected from their respective populations. Since 10 of the 67 joints with an anterior disc position were male, or 15 %, three of the twenty joints selected were from the male sample. Anterior joint space was measured twice on two separate scanned tracings for each of the twenty joints selected. The average anterior joint space (AJS) was 2.74 mm with a standard deviation of 0.95 mm. Loading distance was then determined according to the formula:

$$\text{Loading distance} = 2(\tan(32.5\text{ deg}))(\text{Mean AJS}+2\text{SD}+2\text{Measure error})$$

$$\text{Loading distance} = 2(\tan(32.5\text{ deg}))(2.74\text{ mm} + 2(0.95\text{ mm}) + 2(0.16\text{ mm}))$$

$$\text{Loading distance} = 6.31\text{ mm}$$

The addition of two standard deviations and two measures of error to the mean would yield a conservative boundary for the total error so that at least 95% of the subjects with anterior disc position and virtually all of the subjects with normal disc position would fall into the calculated loading distance.

Reference lines were drawn 3.15 mm superior and 3.15 mm inferior to the eminence loading point perpendicular to an individualized eminence reference and delineated the superior and inferior borders of the eminence loading surface (Figure 2-2).

The points where these two lines intersected the surface of the condyle served as the superior and inferior boundaries of the condylar loading surface. In order to divide the loading surface into superior, central, and inferior sectors, two intermediate lines were drawn 1.05 mm superior and inferior to the eminence loading point and perpendicular to the eminence reference plane (Figure 2-3).

IV. Tomographic Measurements

Determination of tomographic variables involved the digitization of 34 points on the condylar loading surface and 34 points on the eminence loading surface. In addition, the digitization of 6 further points was required for joint space measures. For each tomograph, a total of twelve variables were calculated and are described as follows:

1. Anterior, superior, and posterior joint space (AJS, PJS, and SJS) - Determination of joint space measurements was according to the method of Pullinger and Hollender[6]. (Figure 2-4)
2. Superior, central, inferior and overall condylar loading curvatures - A computer program was developed which used the digitized information to determine the average curvature for each 2.1 mm sector of the loading surface as well as the overall curvature for the entire length of the arc embedded within the 6.3 mm loading distance. A value of zero would indicate a straight line. A positive value would indicate a concave surface and a negative value would indicate a convex surface. Concave would indicate rounded in toward the center of the condyle while convex would indicate rounded outward toward the posterior slope of the eminence. (Figure 2-3)

3. Superior, central, inferior and overall eminence loading curvatures - A computer program was developed which used the digitized information to determine the average curvature for each 2.1 mm sector of the loading surface as well as the entire arc superimposed on the 6.3 mm linear distance. A value of zero would indicate a straight line. A positive value would indicate a convex surface to the posterior slope of the eminence and a negative value would indicate a concave surface to the posterior slope of the eminence. Here, convex would indicate rounded outward toward the condyle while concave can be visualized as rounded inward and away from the condyle. (Figure 2-3)
4. Condylar position - This was calculated according to the method of Pullinger and Hollender[33] through the following formula:

$$(PJS-AJS)/(PJS+AJS) \times 100$$

A zero value indicated a concentric location of the condyle within the fossa. A positive value indicated an anterior and a negative a posterior condylar position.

All tomographic tracings were repeated twice and measured twice. The means of each tomographic variable were used for subsequent statistical evaluation.

2.3 - Analysis of Data

I. Method Error

To determine the error of measurement of angular, linear, and curvature tomographic values, ten tomographic images representative of normal disc position and ten tomographic images representative of disc displacement were randomly traced five times each, and then each tracing was subsequently scanned at 600 dpi and digitized by the principal investigator twice. The standard deviation (SD) of each angular and linear measure was determined over the five tracings of each radiograph. The average SD was determined for the ten joints with normal disc position and anterior disc position separately. Subsequently, the average SD of each angular and linear measure was determined by calculating the average SD value over all twenty radiographs (Table 2-1).

II. Statistical Analysis

Of the 335 joints, 176 joints (106 female and 70 male joints) were used for statistical analysis. Only those joints which fell into the normal disc position or fully displaced disc categories were used. Each joint was considered as a separate case, with right or left joint MRI data matched with the corresponding tomographic angular, linear, and curvature data from the same side. For the purpose of statistical analysis, independence of joints was assumed.

Independent sample t-tests were used to assess whether or not differences in tomographic measurements existed between genders for images representative of normal disc position and those representative of disc displacement. Since the results of the independent sample t-tests indicated that there were significant differences between males and females in the normal disc position grouping, males and females were combined as well as evaluated separately (Table 2-2).

Independent samples t-tests for males and females were conducted for the linear, angular and curvature tomographic variables following removal of outliers. Levene's test for equality of variances was utilized in conjunction with the independent samples t-tests. Joints with normal disc position and those with fully displaced discs were compared by mean. Significance levels of less than 5% were considered to be statistically significant.

2.4 - Results

Descriptive data for the overall, female, and male population according to normal or anterior disc position along with results of independent t-tests can be found in Tables 2-3 through 2-5 respectively. The combined and female sample showed a statistically significant difference among those with normal and anterior disc position for all joint space measures (p value<0.05), condylar position (p value<0.0001), and all four measures of eminence curvature(p value<0.0001). In a similar fashion, males displayed significantly different values for anterior joint space (p value<0.05), superior joint space (p value<0.001), condylar position (p value<0.05), and all four measures of eminence curvature (p value<0.05).

2.5 - Discussion

Objective measurement quantified changes that occur in the osseous tissues with ID. Use of the slope of the articular eminence and the closest anterior joint space prevents the use of cranial and dental reference planes which must be superimposed to the films or assumed to be existent. Thus, the reference system becomes based upon functional rather than anatomic criteria. In addition, objective criteria for loading surface boundaries are given which are repeatable and non-arbitrary in a cross sectional study of this type.

The finding of a statistically significant greater superior joint space values in the male grouping in comparison to females with normal disc position would agree with the findings of Cohlmia et al.[23]. These authors also reported a statistically significant greater superior joint space in a male population than similar female pre-orthodontic population, although their classification criteria did not include a description of disc position. This greater value for superior joint space in the male population could possibly be explained by a greater soft tissue thickness in the male group. Lubsen et al.[34], based on a small sample of 11 males and 10 females, histologically examined the changes in cartilage and subchondral bone during maturation. He found that there were no significant differences between male and female mature condyles, but did find that males retained their "immature" status until a greater age. The immature condyle would be characterized by greater soft tissue thickness, reduced bone thickness and amount, and greater vascular spaces. Another possible explanation could be contributed to the differences in the overall size of the condyle and temporal fossa between males and females in general[24,35,36].

The significant difference in the overall eminence curvature may potentially be explained solely on the basis of positional relationships or anatomical differences between males and females in this area. Ren et al.[37] found that females had a non-significant 4-5 degree reduction in the angle of the eminence. For positional relationships, the superior position of the female condyle relative to the male within the fossa may result in a difference in the eminence loading surface. As the condylar loading point moves superiorly within the fossa, the curvature of the eminence will generally become less convex due to the anatomy of the posterior slope of the eminence.

In keeping with previous studies, it has been shown that anterior disc position results in an increased anterior joint space, reduced superior, and a relative posterior positioning of the condyle within the fossa[1-3]. The posterior joint space was also significantly reduced in the anterior disc position group in the females. Explanation of the statistically significant greater anterior joint space could be explained under three different situations. First, there could be compensatory resorption of the condylar and articular eminence loading surface with anterior disc position. The increased concavity of the eminence in the anterior disc position would support this theory. Secondly, the condyle may be retropositioned within the fossa resulting in an increased anterior joint space. The anterior movement of the thick posterior band to become interposed between the anterosuperior surface of the condyle or the potential deformation of the disc may form the mechanical basis for this observation[38]. The statistical significance and the observed reduction in the posterior joint space for the female and male population respectively would lend support to this idea, although the observed reduction in posterior joint space is only between one and two thirds of the observed increase in anterior joint space. Finally, the increased anterior joint space may be an anatomic variant which is a preexisting and a contributing factor to internal derangement.

The reduced superior joint space in the anterior disc position grouping for both the male and female populations would agree with previous authors[2]. This could be explained through the loss of the posterior band interposed between the condyle and the height of the mandibular fossa.

The relative retrusion of the condyle within the fossa for the anterior disc position grouping was statistically significant for the male and female populations. As discussed previously, this is a relative movement of the condyle as the increase in anterior joint space is only 62 % and 37 % of the decrease in posterior joint space for the female and male population respectively. The hypothesis that condylar retrusion represents a risk factor, through altered biomechanics or impingement of the bilaminar zone that maintains blood flow and nutrition in the joint is neither supported or refuted here. The condylar retrusion here may well be only secondary to altered disc position or a result of increased condylar and eminence remodeling. It may also be due to rotation of the condyle posteriorly in the fossa secondary to a fulcrum effect at the second molar with the loss of the posterior band of the disc from the height of the mandibular fossa and potential shortening of the mandibular ramus characteristic of these patients[39], although one would expect to see an increase in superior joint space if the fulcruming phenomenon were true.

Direct comparison of condylar curvature between joints with normal disc position and those with anterior disc position indicated no significant difference between groups in the male or female population. This varies with the findings of those who suggest that osseous changes in the condyle are indicative of osteoarthritis associated with ID[2,3,7,40,41]. Possible explanations include the possibility that the distribution of forces on the condyle is spread over the entire condylar head and thus forces are not exceeded in comparison to the posterior slope of the eminence[42]. Alternatively, if one is to examine the reference system, the lack of change in the condyle may be due to the observation that the measurement of condylar curvature is insensitive to alterations of the positional relationships of the condyle within the fossa. The condylar load point serves as a starting point for the reference system thus if the condylar load point does not change on the condyle and remodeling does not occur, no change will be seen in condylar curvature even with change in position. Finally, the reference and measurement system may have been deficient in including areas of peripheral remodeling or, osseous changes may be qualitative in nature (sclerosis, change in trabecular pattern, formation of cysts), rather than quantitative in the form of erosions or flattening.

All measures of osseous eminence curvature in the male and female population indicated a statistically significant reduction in convexity of the posterior slope of the loading surface of the eminence. Possible explanations for this would include positional relationships of the condyle within the fossa, or regressive remodeling. Regressive remodeling would agree with those who have found a flattening of the eminence in response to an anterior disc position[37,43]. This could be viewed as an adaptive response to altered disc position in an effort to increase mobility of the condyle in the presence of a chronically anteriorly displaced disc and alter unphysiologic loading patterns[44].

The observation that the condyle and temporal fossa have the potential to undergo significant change in shape during the period from early adolescence to adulthood may account for some of the variation in joint space measurements and measures of morphology [36,45-47]. In addition, variables of craniofacial morphology, growth direction, and malocclusion have been shown by various authors to play a role in positional and morphological relationships of the temporomandibular joint [23,24,26,48,49].

Inherent limitations in the design of the measurement of tomographic variables and application of the reference system were encountered. Difficulties in design included:

- The definition of subjective anterior disc position did not include a classification of reducing, non-reducing, or description of perforation. Non-reducing discs and those with perforation have been shown to be associated with an increased frequency of structural and hard tissue changes in comparison to subjects diagnosed with anterior disc displacement with reduction[1,7,8,50]

- All measurements were made by the same investigator
- The definition of loading distance was an attempt to develop an objective measure of condylar and temporal morphology under static loading conditions[27]. The actual area of loading varies with type of movement, muscle direction, craniofacial morphology, point of bite application, and through the medial, lateral, anterior, and posterior components of the joint *in vivo*[29,51-53].

Challenges encountered in the application of the design included:

- The use of condylar load point and associated reference system may prevent further use in longitudinal studies since it is based on function rather than anatomy.
- Application of this design to the medial and lateral components of the joint may be presumptuous since loading in those components of the joint may not mimic that of the central component[52].

2.6 - Conclusion

An evaluation of an adolescent age group with normal and anterior disc position revealed the following characteristics:

1. Male and female adolescents with normal disc position differ significantly in superior joint space and the curvature of the eminence loading surface.
2. Reduced superior joint space, increased anterior joint space, relative condylar retropositoning, and reduced convexity of the eminence loading surface relative to those with normal disc position characterize adolescent males with anterior disc position.

3. Reduced superior and posterior joint space, increased anterior joint space, relative condylar retropositioning, and reduced convexity of the eminence loading surface relative to those with normal disc position characterize adolescent females with anterior disc position.

The results of this study suggest that joint space and information on the osseous architecture derived from axially corrected tomographic images may provide diagnostic information for the assessment of joint status in an adolescent population.

Table 2-1 Method Error as determined through pilot study of 10 joints representative of normal disc position and 10 joints representative of disc displacement. Average, Maximum and Minimum SD Values for Tomographic Variables

Variable	Average SD*			Maximum SD			Minimum SD		
	Overall	Normal	ADD	Overall	Normal	ADD	Overall	Normal	ADD
Anterior joint space (mm)	0.16	0.16	0.17	0.39	0.39	0.34	0.03	0.06	0.03
Posterior joint space (mm)	0.19	0.19	0.19	0.33	0.31	0.35	0.03	0.03	0.03
Superior joint space (mm)	0.24	0.23	0.24	0.40	0.40	0.38	0.05	0.08	0.05
Condylar position (%)	4.62	4.81	4.43	12.91	12.91	9.40	1.12	2.39	1.12
Superior condylar curvature (1/mm)	0.07	0.07	0.08	0.21	0.12	0.21	0.02	0.02	0.03
Central condylar curvature (1/mm)	0.08	0.08	0.08	0.18	0.16	0.20	0.00	0.00	0.00
Inferior condylar curvature (1/mm)	0.08	0.10	0.07	0.19	0.19	0.13	0.02	0.03	0.02
Overall condylar curvature (1/mm)	0.02	0.02	0.02	0.05	0.04	0.05	0.01	0.00	0.00
Superior eminence curvature (1/mm)	0.08	0.08	0.08	0.23	0.23	0.19	0.01	0.01	0.03
Central eminence curvature (1/mm)	0.08	0.09	0.07	0.17	0.16	0.16	0.02	0.02	0.03
Inferior eminence curvature (1/mm)	0.07	0.06	0.08	0.14	0.09	0.14	0.02	0.02	0.03
Overall eminence curvature (1/mm)	0.02	0.02	0.02	0.05	0.05	0.05	0.01	0.01	0.01

*SD for each radiograph determined over 10 measurements (five tracings of each radiograph measured twice) - Overall SD represents mean of SD's over twenty radiographs. Normal and anterior disc position grouping determined over 10 radiographs. Normal=normal disc position; ADD=anterior disc position.

Table 2 - 2 Variables of Significance for Independent t-tests Between Male and Female Population with Normal Disc Position (n=109)

Variable	n	Mean	SD	Difference	p-value
Superior joint space (mm)					
Female	49	3.42	0.90		
Male	60	3.77	0.6	0.35	0.039
Overall eminence curvature (1/mm)					
Female	49	0.07	0.08		
Male	60	0.10	0.06	0.03	0.026

Table 2-3 Descriptives, Difference Between Means, and Results of Independent t-tests for Females and Males with Normal and Anterior Disc Position (n=176)

Variable	n	Average	SD	Max.	Min.	Observed Mean Difference	p-value
Anterior Joint Space (mm)							
Normal disc position	109	1.92	0.51	3.78	0.75		
Anterior disc position	67	2.67	0.88	4.73	0.94	0.75	<.0001
Posterior Joint Space (mm)							
Normal disc position	109	2.95	0.82	5.86	0.64		
Anterior disc position	67	2.49	0.93	5.35	1.08	0.46	0.001
Superior Joint Space (mm)							
Normal disc position	109	3.62	0.89	7.12	1.64		
Anterior disc position	67	2.46	0.88	5.38	1.12	1.15	<.0001
Condylar position (%)							
Normal disc position	109	20.20	19.50	55.12	-65.97		
Anterior disc position	67	-3.98	24.20	52.12	-51.26	24.18	<.0001
Superior condylar curvature (1/mm)							
Normal disc position	109	-0.19	0.10	-0.01	-0.40		
Anterior disc position	67	-0.21	0.09	-0.01	-0.44	0.02	0.115
Center condylar curvature (1/mm)							
Normal disc position	109	-0.40	0.15	-0.12	-0.72		
Anterior disc position	67	-0.37	0.18	0.08	-0.74	0.03	0.15
Inferior condylar curvature (1/mm)							
Normal disc position	109	-0.03	0.19	0.37	-0.41		
Anterior disc position	67	-0.05	0.20	0.32	-0.52	0.02	0.551
Overall condylar curvature (1/mm)							
Normal disc position	109	-0.22	0.04	-0.15	-0.30		
Anterior disc position	67	-0.21	0.06	-0.02	-0.29	0.01	0.40
Superior eminence curvature (1/mm)							
Normal disc position	109	0.01	0.11	0.35	-0.34		
Anterior disc position	67	-0.12	0.10	0.18	-0.30	0.13	<.0001
Center eminence curvature (1/mm)							
Normal disc position	109	0.14	0.13	0.45	-0.19		
Anterior disc position	67	-0.02	0.13	0.35	-0.26	0.16	<.0001
Inferior eminence curvature (1/mm)							
Normal disc position	109	0.15	0.10	0.34	-0.13		
Anterior disc position	67	0.06	0.10	0.27	-0.24	0.09	<.0001
Overall eminence curvature (1/mm)							
Normal disc position	109	0.08	0.07	0.22	-0.10		
Anterior disc position	67	-0.04	0.06	0.19	-0.16	0.12	<.0001

Table 2-4 Descriptives, Difference Between Means, and Results of Independent t-tests for Females with Normal and Anterior Disc Position (n=106)

Variable	n	Average	SD	Max.	Min.	Observed Mean Difference	p-value
Anterior Joint Space (mm)							
Normal disc position	49	1.99	0.56	3.78	1.18		
Anterior disc position	57	2.63	0.84	4.69	0.94	0.64	<.0001
Posterior Joint Space (mm)							
Normal disc position	49	2.86	0.74	4.64	1.41		
Anterior disc position	57	2.46	0.90	5.35	1.08	0.40	0.015
Superior Joint Space (mm)							
Normal disc position	49	3.42	0.90	6.45	1.64		
Anterior disc position	57	2.41	0.84	5.38	1.12	1.01	<.0001
Condylar position (%)							
Normal disc position	49	17.36	18.00	55.12	-17.45		
Anterior disc position	57	-3.80	24.60	52.12	-46.11	21.16	<.0001
Superior condylar curvature (1/mm)							
Normal disc position	49	-0.19	0.10	-0.01	-0.39		
Anterior disc position	57	-0.21	0.09	-0.01	-0.44	0.02	0.19
Center condylar curvature (1/mm)							
Normal disc position	49	-0.39	0.15	-0.03	-0.72		
Anterior disc position	57	-0.37	0.19	0.08	-0.74	0.02	0.501
Inferior condylar curvature (1/mm)							
Normal disc position	49	-0.04	0.20	0.26	-0.41		
Anterior disc position	57	-0.04	0.20	0.32	-0.52	0.00	0.878
Overall condylar curvature (1/mm)							
Normal disc position	49	-0.22	0.04	-0.09	-0.30		
Anterior disc position	57	-0.21	0.06	-0.02	-0.29	0.01	0.434
Superior eminence curvature (1/mm)							
Normal disc position	49	0.00	0.12	0.35	-0.26		
Anterior disc position	57	-0.13	0.09	0.18	-0.30	0.13	<.0001
Center eminence curvature (1/mm)							
Normal disc position	49	0.11	0.15	0.45	-0.19		
Anterior disc position	57	-0.02	0.12	0.35	-0.26	0.13	<.0001
Inferior eminence curvature (1/mm)							
Normal disc position	49	0.15	0.12	0.34	-0.13		
Anterior disc position	57	0.06	0.10	0.27	-0.24	0.09	<.0001
Overall eminence curvature (1/mm)							
Normal disc position	49	0.07	0.08	0.21	-0.10		
Anterior disc position	57	-0.04	0.06	0.19	-0.16	0.11	<.0001

Table 2-5 Descriptives, Difference Between Means, and Results of Independent t-tests for Males with Normal and Anterior Disc Position (n=70)

Variable	n	Average	SD	Max.	Min.	Observed Mean Difference	p-value
Anterior Joint Space (mm)							
Normal disc position	60	1.86	0.47	2.81	0.75		
Anterior disc position	10	2.91	1.11	4.73	1.27	1.05	0.015
Posterior Joint Space (mm)							
Normal disc position	60	3.03	0.88	5.86	0.64		
Anterior disc position	10	2.64	1.14	5.06	1.36	0.39	0.22
Superior Joint Space (mm)							
Normal disc position	60	3.78	0.86	7.12	2.37		
Anterior disc position	10	2.77	1.00	4.36	1.17	1.01	.001
Condylar position (%)							
Normal disc position	60	22.52	20.54	50.61	-65.79		
Anterior disc position	10	5.59	23.76	39.51	-51.26	16.93	0.021
Superior condylar curvature (1/mm)							
Normal disc position	60	-0.17	0.10	-0.01	-0.40		
Anterior disc position	10	-0.22	0.10	-0.08	-0.35	0.05	0.113
Center condylar curvature (1/mm)							
Normal disc position	60	-0.41	0.15	-0.12	-0.72		
Anterior disc position	10	-0.35	0.15	-.212	-0.67	0.06	0.23
Inferior condylar curvature (1/mm)							
Normal disc position	60	-0.03	0.18	0.37	-0.37		
Anterior disc position	10	-0.11	0.19	0.17	-0.39	0.08	0.23
Overall condylar curvature (1/mm)							
Normal disc position	60	-0.22	0.04	-0.15	-0.28		
Anterior disc position	10	-0.22	0.05	-0.15	-0.27	0.00	0.815
Superior eminence curvature (1/mm)							
Normal disc position	60	0.02	0.11	0.27	-0.34		
Anterior disc position	10	-0.07	0.11	0.14	-0.20	0.09	0.015
Center eminence curvature (1/mm)							
Normal disc position	60	0.16	0.10	0.41	0.00		
Anterior disc position	10	-0.03	0.16	0.34	-0.22	0.19	<.0001
Inferior eminence curvature (1/mm)							
Normal disc position	60	0.15	0..08	0.34	-0.02		
Anterior disc position	10	0.06	0.09	0.20	-0.09	0.08	0.005
Overall eminence curvature (1/mm)							
Normal disc position	60	0.10	0.06	0.22	-0.04		
Anterior disc position	10	-0.03	0.08	0.12	-0.14	0.12	0.028

Figure 2-1 Posterior slope of the articular eminence

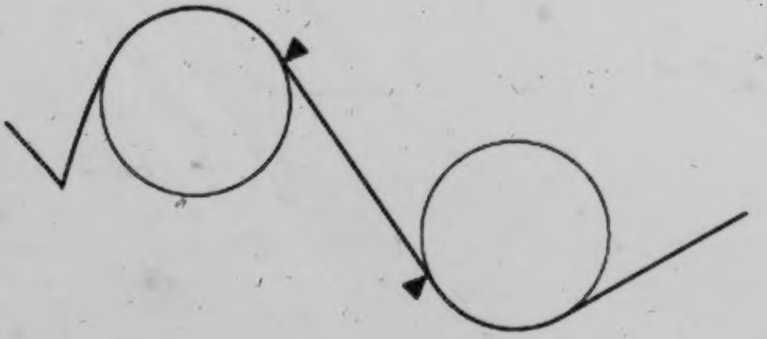


Figure 2-2 Geometrical relationships in calculation of loading distance; Condylar Load Point (CLP), Anterior Joint Space (AJS)

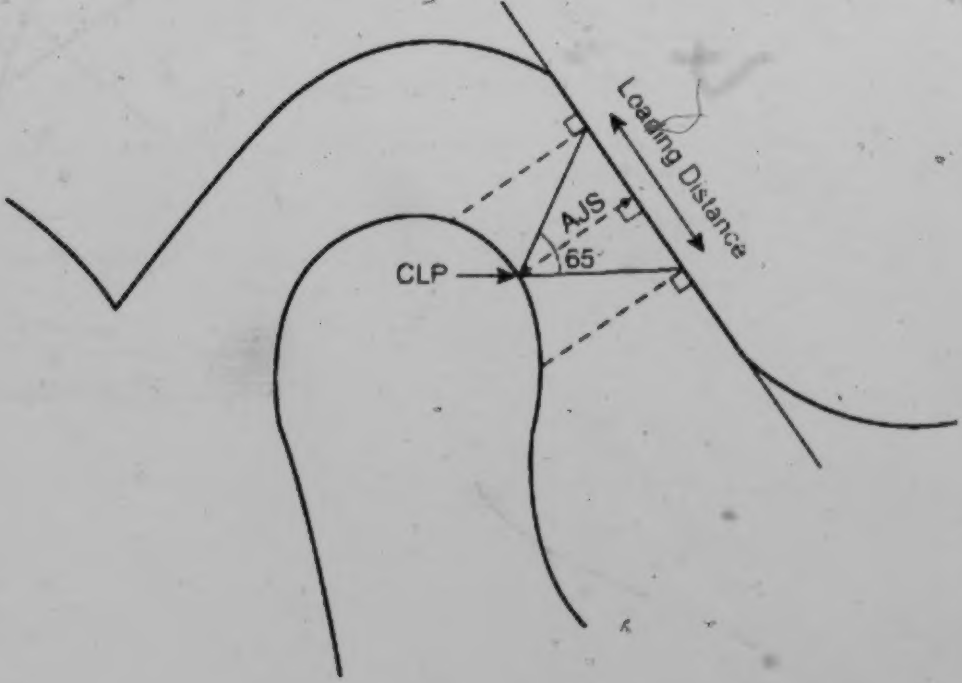

Loading Distance
AJS
65
CLP

Figure 2-3 Delineation of overall, superior, central, and inferior sectors of loading surface

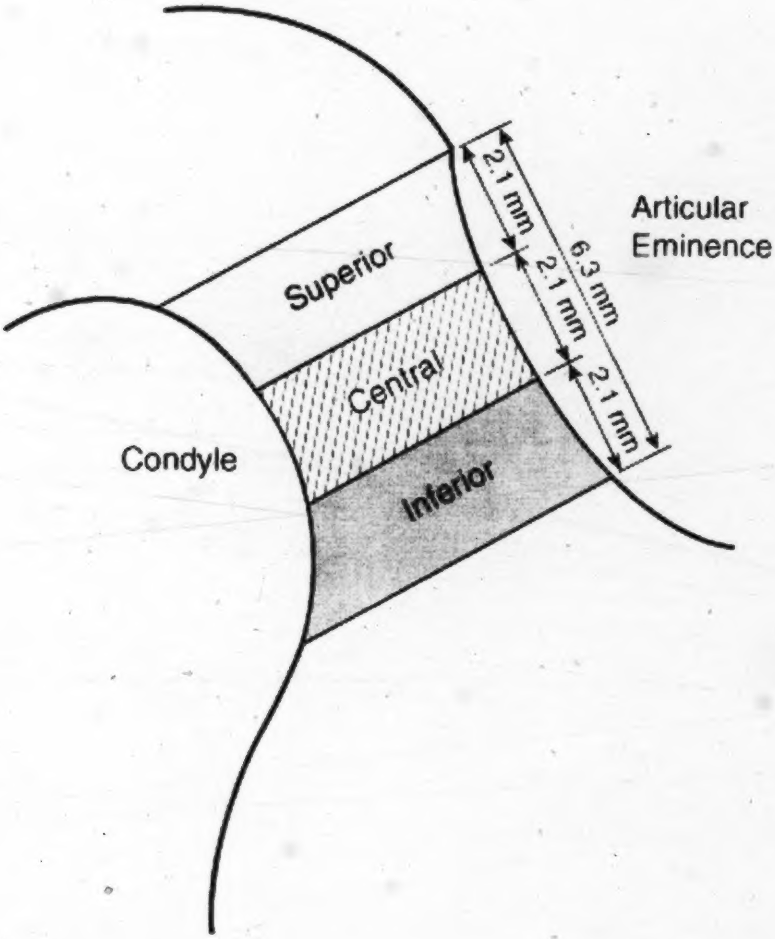
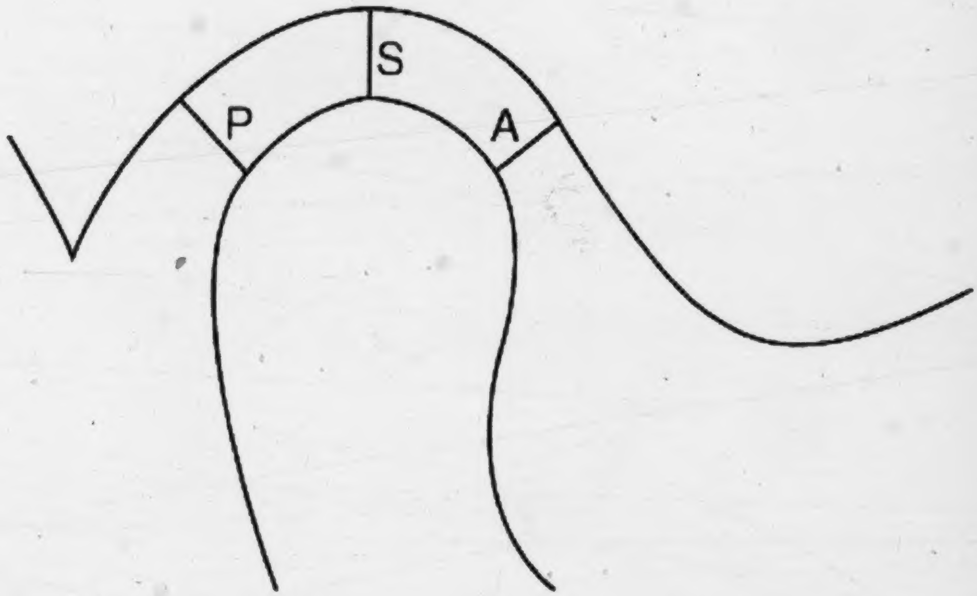

2.1 mm
6.3 mm
2.1 mm
2.1 mm
Articular
Eminence
Superior
Central
Inferior
Condyle

Figure 2-4 Locations of measurements of closest anterior (A), posterior (P) and superior (S) interarticular spaces in temporomandibular joint tomograms



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Chapter Three

Research Paper #2

Joint Space and Osseous Morphology Associated with Adolescent TMJ Disc Status

3.1 - Introduction

The signs and symptoms of temporomandibular disorders (TMD) are evident early in adolescence. The incidence of joint sounds has been reported to range from 10-20% and the overall incidence of symptoms ranges from 30-60%[1-6]. Females and older adolescents have a higher prevalence of signs and symptoms[2,7]. Although the early detection of TMD is of value, studies have shown that signs and symptoms of TMD in children are a poor predictor for their occurrence in adulthood[8]. Magnusson et al.[9], in a 5-year longitudinal study of adolescents at the ages of 15 and 20 years, found no change in TMD signs and symptoms between examinations in nearly half the individuals. For the entire study population, 31% had joint sounds at the age of 15 and 34% at the age of 20 years.

Clinical and epidemiological studies into the prevalence of TMD in the adult and adolescent population are of academic value but definitive diagnosis of internal derangement (ID) is only possible through soft tissue imaging of the temporomandibular joint (TMJ) by magnetic resonance imaging (MRI) or arthrography. Paesani et al.[10] reported the diagnostic accuracy of clinical examination alone to only be 43% in comparison to imaging findings with arthrography or MRI. Roberts et al.[11] had a diagnostic accuracy of 59% in a similar study. Thus, in order to evaluate the correlation of joint space and osseous changes associated with ID, appropriate soft tissue imaging must be utilized.

With respect to osseous morphology of the articular eminence and the condyle, research indicates that there may be an association with tomographic morphological findings and soft tissue imaging evidence of disc displacement. For the articular eminence, the findings of Panmekiate et al.[12] indicate that the posterior slope of the articular eminence is less prominent in those with anterior disc displacement (ADD) without reduction than in normal and reducing joints. Ren et al.[13] found that the steepness of the articular eminence was greater in 34 asymptomatic volunteers than in 71 patients with ID as diagnosed with dual space arthrography. The steepness was a statistically significant 5 to 9 degrees less prominent respectively, in the joints with ADD with reduction and ADD without reduction. The results imply that the angle of the articular eminence is reduced in the patients as a result of the remodeling or degenerative changes of the bone subsequent to ID or that a flattened articular eminence may be a risk factor for ID.

For the condyle, Kirk[14] found that joints with MRI evidence of total disc dislocation showed bony evidence of degenerative changes with tomography in a sample of 35 joints. In addition, joints with superior disc position or with ADD with reduction had no osseous changes suggestive of degenerative joint disease. Ren et al.[15] found the presence of subjectively evaluated osseous changes to be significantly greater in patients with ADD without reduction than with reduction (43.8% vs. 10.8%). With MRI's, Rao et al.[16] examined 276 TMJ's in 138 symptomatic patients to correlate their findings with ID. The condyle was abnormal in 98 of the 276 joints with 94 of the joints with abnormal condyles diagnosed as internally deranged. Of the total 181 joints with ID, condylar morphology was normal in 50% and altered in 50%. Bony changes were seen in 65% of joints with ADD without reduction and 45% of joints with ADD with reduction. Anderson and Katzberg[17] found that the incidence and severity of the degenerative changes on tomographs was positively correlated with the arthrographic assessment of the degree of soft tissue injury in a sample of 141 patients. Thus, research suggests that there may be osseous changes in axially corrected tomograms suggestive of ID and there appears to be a potential correlation between the severity of ID and regressive condylar bony remodeling in the adult population.

The majority of studies utilizing MRI or arthrography as a gold standard to evaluate spatial changes with ID have been conducted in the adult population. Brand et al.[18], used subjective evaluation of condylar position on tomograms with arthrographic interpretation of disc position, found that in the absence of tomographic evidence of degenerative joint disease, a statistically significant 88 to 90% of the cases with ADD had condyles which were retropositioned in the fossa while only 42% of the cases with normal arthrograms had posterior displacement of the condyle. Ren et al.[15] found that the mean condylar position was significantly more posterior in lateral tomograms of joints diagnosed as ADD with and without reduction. There was no significant difference for average condylar position between normal disc position and ADD with reduction alone. Similar findings were found by Kirk[14] with respect to superior joint space.

Despite the findings that evaluation of joint space and condylar position may be diagnostic of ID, others have questioned the diagnostic value of joint space measurements. Katzberg[19] failed to find a significant difference between joints with documented ID and those with clinically and arthrographically normal disc position with respect to condylar position in the fossa. Furthermore, Hatcher et al.[20] have suggested that a three dimensional analysis of joint space may be required since the morphology of the condyle does not always replicate that of the fossa and this may alter apparent joint space dimensions in the lateral, central, and medial components of the joint. In addition, the measurement of joint space is subject to significant variation in the normal population which may preclude it's use as a diagnostic tool [21,22].

Despite these findings, there may be value in the assessment of joint space and condylar position in an adolescent group. There is a paucity of literature with respect to the assessment of joint space in an adolescent age group with respect to the position and the morphology of the disc within the TMJ. This data may provide information on: normal anatomy of the developing TMJ, how the joint space in adolescents with normal and altered disc position and morphology compares to their adult counterparts, provide other investigators with a baseline of normal, and give clues to differences in the development of the TMJ for those with and without derangement.

The purpose of this retrospective research study was to objectively determine if temporomandibular disc displacement and deformation, as identified with MRI, is associated with specific positional and morphological characteristics of the osseous components of the TMJ as viewed in axially corrected tomographs of an adolescent sample. The results may validate the usefulness of tomographic radiographs in the identification of joint abnormalities in an adolescent population. In addition, information derived from this study may lead to an enhanced understanding of some of the contributing factors as well as sequelae to ID in an adolescent population.

3.2 - Materials and Methods

Axially corrected tomographic radiographs and MRI of 335 TMJ's in 175 subjects (106 female and 69 male) between the ages of 7.27 - 20.0 years (mean age 13.08 yrs) were used for this study. Mean male age was 13.02 years and mean female age was 13.12 years. Subjects consisted of individuals who presented sequentially to a private imaging facility for orthodontic records, regardless of TMJ status, and from whom consent was obtained for participation in the study.

I. Tomographic Technique

All tomographic images were exposed at the same private imaging facility using a Tomax Ultra-scan x-ray machine (Incubation Industries, Inc., 429 Easton Road, Warrington, Pa, 18976). Exposure settings were at 100 milliseconds, 5 mA and 78 kVp. Head positioning was established by alignment of Frankfort plane parallel to the plane of the film with the teeth in maximum intercuspation making use of a polyvinylsiloxane (President Jet - Bite, Coltene / Whaledent Inc., Mahwah, New Jersey) centric occlusion bite registration. Source to earrod distance was 71.1 cm and earrod-to-film distance was 12.7 cm.

All tomographic radiographs were viewed under standardized conditions and traced onto acetate overlays using a 0.3 mm diameter lead pencil. Each central slice of the tomographic survey was traced at least one week apart by the principal investigator and involved the identification of the outline of the mandibular condyle and glenoid fossa. The central slice of the tomographic survey was used for this study. Each tracing was scanned by the same investigator at 600 dpi using a UMAX 1200S scanner (Taiwan). A computer program was written in Microsoft Visual Basic for Windows (Microsoft Corporation, Washington, DC) which interpreted data entered and returned angular, curvature, and distance measurements. The curvature calculation was validated through the repeated measurement of known polynomial curves at known locations. The average curvature calculation was verified by repeated measurements of varying radii. For both measures the calculated variance was less than 1% of actual values.

II. Determination of Loading Distance

Determination of the loading surfaces of the condyle and the posterior slope of the articular eminence was based on the biomechanical model of Smith et al.[23]. It was assumed that condylar reaction forces during maximum intercuspation were directed essentially perpendicular to the posterior slope of the articular eminence[23-27] and that the condylar loading point corresponded with the closest joint space perpendicular to the posterior slope of the articular eminence[26]. Except in few joints with extensive condylar and posterior slope flattening, the visual identification of anterior joint space was straightforward. In those problem cases, the center point of the flat region was used.

Condylar reaction forces were assumed to act through an angle of 32.5 degrees superior and 32.5 degrees inferior to the perpendicular to the posterior slope of the articular eminence through the condylar loading point during unilateral biting[23]. In order to develop a loading distance for the purposes of this study, 10 female and 10 male joints representative of normal disc position and, 10 female and 9 male joints representative of disc displacement were randomly selected. Only TMJ's from separate patients were considered. The closest anterior joint space was measured perpendicular to the posterior slope of the articular eminence. The posterior slope of the articular eminence was identified by two circles with closest fit to the glenoid fossa and the articular tubercle, respectively. The inflection of the posterior slope of the posterior slope of the eminence from the circle circumferences provided two points to include a single tangent to the circles, which was parallel to the articular eminence (Fig 3-1)[28]

The error of measurement was determined by selecting 10 tomographic images representative of normal disc position and 10 representative of disc displacement. These twenty tomographic images were traced five times, scanned at 600 dpi, and the closest anterior joint space was measured twice on each image. The standard deviation (SD) of the linear measure was determined over the five tracings of each radiograph. Subsequently, the average SD for each angular and linear measure was determined by calculating the average SD value over all twenty radiographs (Table 3-1).

Independent t-tests comparing gender in those with normal and anterior disc position (abnormal group) indicated no significant differences with respect to anterior joint space ($p>.05$). Since the anterior joint space for the abnormal group was significantly greater than for the normal group ($p<.05$), the abnormal group was used for the determination of the loading distance. Three male and seventeen female TMJ's with anterior disc position were randomly selected from their respective populations. Since 10 of the 67 joints with an anterior disc position were male, or 15 %, three of the twenty joints selected were from the male sample. Anterior joint space (AJS) was measured twice on two separate scanned tracings for each of the twenty joints selected. The average anterior joint space was 2.74 mm with a standard deviation of 0.95 mm. Loading distance was then determined according to the formula (Figure 3-2):

$$\text{Loading distance} = 2(\tan(32.5\text{ deg}))(\text{Mean AJS}+2\text{SD}+2\text{Measure error})$$

$$\text{Loading distance} = 2(\tan(32.5\text{ deg}))(2.74\text{ mm} + 2(0.95\text{ mm}) + 2(0.16\text{ mm}))$$

$$\text{Loading distance} = 6.31\text{ mm}$$

The addition of two standard deviations and two measures of error to the mean would yield a conservative boundary for the total error so that at least 95% of the subjects with anterior disc position and virtually all of the subjects with normal disc position would fall into the calculated loading distance.

Reference lines were drawn 3.15 mm superior and 3.15 mm inferior to the eminence loading point perpendicular to an individualized eminence reference and delineated the superior and inferior borders of the eminence loading surface (Figure 3-2). The points where these two lines intersected the surface of the condyle served as the superior and inferior boundaries of the condylar loading surface. In order to divide the loading surface into superior, central, and inferior sectors, two intermediate lines were drawn 1.05 mm superior and inferior to the eminence loading point and perpendicular to the eminence reference plane (Figure 3-3).

III. - Tomographic Measurements

Determination of tomographic variables involved the digitization of 34 points on the condylar loading surface and 34 points on the eminence loading surface. In addition, the digitization of 6 further points was required for joint space measures. For each tomograph, a total of ten variables were calculated and are described as follows:

1. Anterior, superior, and posterior joint space (AJS, SJS, and PJS) - Determination of joint space measurements was according to the method of Pullinger and Hollender[29]. (Figure 3-4)
2. Superior, central, and inferior condylar loading curvatures - A computer program was developed which used the digitized information to determine the average curvature for each 2.1 mm sector of the loading surface. The boundaries of these loading surfaces were described earlier. A value of zero would indicate a straight line. A positive value would indicate a concave

surface and a negative value would indicate a convex surface. Concave would indicate rounded inward toward the center of the condyle and convex rounded outward toward the posterior slope of the eminence. (Figure 3-3)

3. Superior, central, and inferior eminence loading curvatures - A computer program was developed which used the digitized information to determine the average curvature for each 2.1 mm sector of the loading surface. A value of zero would indicate a straight line. A positive value would indicate a convex surface to the posterior slope of the eminence and a negative value would indicate a concave surface to the posterior slope of the eminence. (Figure 3-3)

All tomographic tracings were repeated twice and measured twice. The means of each tomographic variable were used for subsequent statistical evaluation.

When gender was included as an independent variable, females were assigned a value of 1 and males a value of 2.

IV. MRI Measurements

MRI of the TMJ's were performed without sedation using a 1.0 T magnet (Shimadzu Corporation 3, Kanda-Nishikicho 1-chrome, Chiyoda-Ku, Tokoyo 101, Japan) and a unilateral 3 inch surface receiver coil. Axial scout images were obtained to identify the condyles. Bilateral closed mouth sagittal sections were obtained perpendicular to the long axis of the condyle making use of the same polyvinylsiloxane centric occlusion bite registration utilized for the tomographic survey. T1 - weighted 500/20 (TR ms/TE ms) pulse sequences were performed on all subjects using a 3 mm slice thickness, 140 mm field of view, NEX of 2, and an image matrix of 204 x 204.

Sagittal images of the TMJ were produced from 3 mm thick volume slices of the joint and the central slice was chosen which provided identification of both soft tissue and osseous components on each slice. An investigator (B.N.) traced the outline of the articular structures as well as the articular disc of each image. Disc displacement and disc length values were determined for each joint by establishing a standardized eminence reference plane, which represented the longest posterior slope of the articular eminence, as previously described by Nebbe et al.[28]. The Eminence Reference Plane (ERP) is defined as being 50 degrees to Frankfort Horizontal at a point 10.0 mm anterior to the maximum height of the glenoid fossa (Figure 3-5). Three points were defined on the articular disc and one point was defined on the condylar head. These points consisted of the anterior and posterior bands, the midpoint of the disc, and a point on the head of the condyle termed the condylar load point (CLP). The CLP represented the closest joint space between the head of the condyle and the posterior slope of the articular eminence. All four points were projected onto the eminence reference plane by making use of perpendicular lines from the identified points to the ERP. This allowed for disc displacement and disc length measurements. Disc displacement was measured as the distance from the midpoint of the disc to the condylar load point along the eminence reference plane, and disc length was measured as the distance between the midpoints of the anterior and posterior bands, also measured along the eminence reference plane (Figure 3-6)[28]. For the purposes of this study, only data from the slice most representative of the central portion of the TMJ was used.

3.3 - Analysis of Data

I. Method Error

To determine the error of measurement of angular, linear, and curvature tomographic values, ten tomographic images representative of normal disc position and ten tomographic images representative of disc displacement were each randomly traced five times each and then scanned by the principal investigator at 600 dpi and digitized. The standard deviation (SD) of each angular and linear measure was determined over the five tracings of each radiograph. Subsequently, the average SD of each angular and linear measure was determined by calculating the average SD value over all twenty radiographs (Table 3-1).

The reliability of obtaining the eminence reference plane on MR images was determined by randomly selecting twenty-five MRI's and retracing the required landmarks. Dahlberg's formula[30] for determination of the standard error was applied for double determinations, and the standard error was expressed in degrees (Table 3-2).

Determination of reliability in the measurement of disc length and disc displacement was determined by selecting ten MRI's representative of normal disc position and ten representative of disc displacement. These twenty MRI's were randomly traced five times each on consecutive days to determine measurement error. Multivariate ANOVA procedure with MRI's and tracings as factors were utilized to generate a F-statistic and determine the coefficient of intra-rater reliability ($R=1-1/F$) for disc length and disc displacement[31] (Table 3-3).

II. Statistical Analysis

Of the 175 subjects which were imaged, all but 15 (4 male and 11 female) had complete bilateral data sets available. For these 15 patients, only data from one joint was used. Thus, 335 joints (201 female and 134 male joints) were used for statistical analysis. Each joint was considered as a separate case, with right or left joint MRI data matched with the corresponding tomographic angular, linear, and curvature data from the same side. For the purpose of statistical analysis, independence of joints was assumed.

Correlation coefficients were calculated to assess the relationship between all independent and joint status variables for males, females, and the entire sample (Appendix). A stepwise linear regression analysis was used to assess the predictability of joint status from condylar and eminence curvature, joint space, and loading angle. Disc length and disc displacement represented the dependent variables. The relation between the independent variables representative of condylar curvature, eminence curvature and joint space as three discrete groups. A stepwise linear regression analysis was then computed for the entire study population using age, gender, and the angular difference in the loading surfaces as independent variables in addition to the nine measured variables on the tomographic images. Finally, the same statistical analysis previously described was conducted for the male and female population separately since the variable of gender indicated a significant association in the overall regression analysis.

3.4 - Results

I. Combined sample

Descriptive statistics for the overall sample are found in Table 3-4.

Disc displacement as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-5 together with p-values and regression coefficients. Stepwise linear regression analysis showed a negative regression coefficient (-5.49, $p<.001$) for the superior condylar curvature with a very low R-square value (0.04) when the condylar variables were considered independently. For the eminence curvature variables, all three curvatures displayed a negative association ($p<0.05$) with disc displacement indicating an increased concavity to the eminence surface as disc displacement increased. All joint space variables were significant ($p<0.0001$) when considered as a group with AJS and PJS displaying a positive association and SJS indicating a negative association. Although the multiple regression coefficient effect of PJS is positive (0.78) with AJS and SJS are included as independent variables, the observed correlation coefficient between PJS and disc displacement is negative (-0.15). R-square value was 0.36. When all eleven potential independent variables were entered into the model, including the variables of age and gender, all three joint space variables, central and inferior eminence curvature, and gender were included in the model. R-square value for the eleven variables was 0.42.

Disc length as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-5 together with p-values and regression coefficients. Stepwise linear regression analysis indicated a negative regression coefficient (-2.37, $p<0.01$) for the central condylar curvature with a very low R-square value (0.02) when the condylar variables were considered independently. For the eminence curvature variables, all three eminence curvatures displayed a positive association (2.41 - 4.12, p<0.05) with disc length indicating an increased convexity to the eminence surface with increasing disc length. All joint space variables were significant (p<0.0001) when considered as a group with AJS and PJS displaying a negative association (-0.62 and -0.77 respectively, p<0.0001) and SJS indicating a positive association (1.33, p<0.0001). As with disc displacement, the correlation coefficient between PJS and disc length (0.08) is the inverse of that in the regression coefficient. R-square value was 0.23. When all eleven independent variables were entered into the model, the same variables which were included in the displacement model are significant. R-square is 0.27 for the eleven independent variables.

Since the independent variable of gender indicated a statistically significant negative and positive association with disc displacement and disc length respectively (-0.91 and 0.49, p<0.05), the identical regression analysis was conducted for the male and female population as it was for the combined sample.

II. Male population

Descriptive statistics for the male sample are provided in Table 3-6.

Disc displacement as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-7 together with p-values and multiple regression coefficients. Stepwise linear regression analysis showed a negative association for the superior condylar curvature (-4.12, p<0.05) with a very low R-square value (0.05) when the condylar variables were considered independently. For the eminence curvature variables, the central eminence curvature displayed a negative association (-7.42, $p<0.0001$) with disc displacement indicating a decreasing convexity to the eminence surface with increased displacement. All joint space variables were significant when considered as a group with AJS and PJS displaying a positive association (1.11, $p<0.0001$ and 0.50, $p<0.05$ respectively) and SJS indicating a negative association (-0.90, $p<0.0001$). The multiple regression coefficient effect of PJS is positive when SJS and AJS are included in the model. However, the observed correlation coefficient between PJS and displacement is negative (-0.16). R-square-value was 0.35. When all ten independent variables were used in the regression, all three joint space measures and the central eminence curvature were included in the model. R-square was 0.41 with the direction of each significant variable remaining identical to when each group was considered independently.

Disc length as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-7 together with p-values and regression coefficients. For the eminence curvature variables, the central eminence curvature displayed a positive association (4.95, $p<0.0001$) with disc length indicating an increasing convexity to the eminence surface with increasing disc length. When only the joint space variables were considered, SJS and AJS were significant with a positive (0.65, $p<0.0001$) and negative (-0.48, $p<0.01$) association respectively. When all ten independent variables were entered into the model, only SJS and AJS were included in the model. R-square was 0.16 for the joint space grouping and overall, with the regression coefficients remaining identical to when joint space was considered as an isolated grouping.

III. Female population

Descriptive statistics for the female sample are found in Table 3-8.

Disc displacement as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-9 together with p-values and regression coefficients. Stepwise linear regression analysis showed a negative association for all eminence curvatures with a R-square value of 0.24 when the eminence variables were considered independently. This would indicate a reduced convexity to the eminence surface with increasing displacement. All joint space variables were significant when considered as a group with AJS and PJS displaying a positive association (1.49 and 0.96 respectively, $p<0.0001$) and SJS indicating a negative association (-1.68, $p<0.0001$). Not unlike the male population, the observed correlation coefficient between PJS and disc displacement is negative (-0.11). The R-square value was 0.33. When all ten independent variables were entered into the model, all three joint space measures and inferior eminence curvature were significant. R-square was 0.38 with the direction of associations remaining identical to when each group was considered independently.

Disc length as dependent variable

Results of the stepwise linear regression analysis are provided in Table 3-9 together with p-values and regression coefficients. Stepwise linear regression analysis showed a negative association (-2.66, $p<0.05$) for the central condylar curvature with a very low R-square value (0.03) when the condylar variables were considered independently. For the eminence curvature variables, all three eminence curvatures had a positive association indicating increased convexity with increased disc length and an R-square value of 0.22. All joint space variables were significant when considered as a group with AJS and PJS displaying a negative association (-0.67 and -1.01 respectively, $p<0.0001$) and SJS indicating a positive association (1.55, $p<0.0001$) with disc length. As with displacement, the positive correlation coefficient between PJS and disc displacement should be noted (0.04). R-square value was 0.24. When all ten independent variables were entered into the model, all three joint space measures, inferior eminence curvature, and a negative association for patient age when included in the model. R-square was 0.32 with the direction of associations remaining identical to when each group was considered independently.

3.5 - Discussion

According to the multiple regression coefficient as found in the regression for entire sample, there would be a tendency for females to have a greater association with anterior disc displacement or reduced disc length. Since gender had a statistically significant multiple regression coefficient, it would follow that the male and female population should be examined separately. This finding would agree with those who have suggested a predominance of females in populations with TMD[2,7,32,33], and those who have found a predominance of females with disc displacement at autopsy[34].

A weak, but statistically significant association indicated for superior condylar curvature in the male and overall population as a predictor of disc displacement. With disc length as a dependent variable, central condylar curvature was predictive. The increase in superior condylar curvature with disc displacement could be explained by potential peripheral remodeling on the superior surface of the condyle in an effort to increase the area of loading on the condyle or by regressive remodeling on the loading surface of the condyle[35]. The increased convexity of the central condylar curvature for increased disc length would be expected as flattening would be associated with reduced disc length. This would agree with the findings of Westesson and Rohlin[36] who found that the morphology of the disc was highly correlated with disc displacement and osteoarthrosis in a sample of 127 temporomandibular joint autopsy specimens.

The statistically significant negative association for all three eminence curvatures associated with disc displacement for the female and combined sample and positive association with disc length in the respective populations may be explained by either a positional anomaly of the condyle within the fossa with the changes in disc status or by regressive remodeling of the osseous surface of the articular eminence. Since the SJS is reduced with disc displacement and decreased disc length, the position occupied by the condyle within the fossa dictates a superior movement of the condylar load point within the fossa. The anatomy of the fossa dictates a relative reduction in the convexity to the posterior slope as the condylar load point moves superiorly. This observation suggests that this reduction in convexity is purely due to changes in the positional relationship of the condyle within the fossa. This may also explain why there is only a weak association of change in condylar morphology as the condylar load point forms the starting point of the reference system.

An alternative explanation is that regressive remodeling is occurring on the posterior slope of the eminence as an adaptive response to disc displacement and changes in disc length in an effort to maintain and enhance the function of the TMJ due to the altered loading environment of ID[37,38]. Several authors have suggested that the initial remodeling changes associated with ID occur in the temporal component of the joint, although they may be masked by compensations in the overlying articular soft tissue upon macroscopic examination[39-42].

For the male population, only the central eminence curvature indicated a reduced convexity with increased disc displacement and reduced disc length. This could be once again explained by positional relationships or regressive remodeling. With respect to why the superior and inferior eminence curvatures did not contribute to the prediction of joint status in males and they did in females, there are three possible explanations. First, the relative immaturity and resultant increased cellularity of the male articular tissues in relation to females may allow the increased adaptive capacity to maintain the existing morphology in the presence of altered loading conditions secondary to disc displacement and changes in disc morphology in males[43]. Secondly, the central loading surface of the eminence may experience increased loads relative to the superior and inferior areas, since this is the area that would be most heavily loaded during centric clenching as determined through static force analysis in mathematical models[23,44]. Finally, disc displacement without reduction and with perforation is associated with greater osseous changes than disc displacement with reduction[17,18,45,46]. No indication is given in the joint status variables for discs with and without reduction. It may be possible that there were fewer joints in the male population that had non-reducing or perforated discs, thus fewer signs of secondary osteoarthritis.

The negative association of SJS with disc displacement can be explained by loss of the posterior band of the disc interposed between the superior surface of the condyle and the height of the mandibular fossa. Alternatively, the change in the shape of the disc from biconcave to biconvex in association with disc displacement may also contribute to the observed trend in SJS values [36,45,47]. For AJS, either retropositioning of the condyle within the fossa secondary to disc displacement and deformation or regressive remodeling of the loading surface of the condyle and articular eminence may explain the observed correlation. Finally, the reduced PJS with displacement may be secondary to condylar retropositioning within the fossa with displacement.

The predictive association with the joint space variables remains the same for correlation coefficients and multiple regression coefficients for all of the independent variables except PJS when one looks at the regression models. The PJS value takes on the reciprocal sign in the model as that of the correlation coefficient when AJS and SJS are included as independent variables. The high correlation coefficient between SJS and PJS may provide evidence for this effect ($r = 0.57$ to 0.63, refer to appendix).

The increase in AJS, whether due to regressive remodeling of the loading surfaces with displacement or retropositioning of the condyle within the fossa may serve as an adaptive mechanism to alter joint loading. First, by increasing the AJS, the condylar load will be distributed over a greater surface area. This may be viewed as an effort to reduce loading in the absence of the disc and inherent stress distributing properties. Finally, if the increased AJS is due to regressive remodeling of the eminence, this may enhance mobility by allowing obstruction free movement of the condyle beyond discal deformations and positional obstructions[48,49] and secondly cause the condylar reaction forces to be directed further inferiorly[50].

Examination of the independent variables in the overall regression with a predictive association for joint status varied in each sample and with each joint status variable. For the female population, all three joint spaces and inferior eminence curvature were consistent among displacement and disc length. For disc length, age was significant. The association with age is difficult to explain, but may be related to the chronicity of the displacement. It has been suggested that displacement precedes deformation of the morphology of the disc. As a result, the time dependent deformation of the disc may be evident in this young sample of subjects[51].

For the male sample, only SJS and AJS were predictive of disc length, where as for displacement, all three joint spaces and the central eminence curvature were included. The associations for these variables have been previously discussed.

For the combined sample, the inclusion of gender for predictive association of disc displacement and disc length would support the work of other investigators who have found a predominance of females with osseous changes relative to ID.

3.6 - Conclusions

An examination of osseous morphology and spatial relationships in relation to disc displacement and disc length in an adolescent population revealed the following:

1. Males and females had a statistically significant difference in superior joint space in subjects with normal disc position.
2. As disc displacement increases and disc length decreases, the convexity of the posterior slope of the articular eminence is reduced relative to the condylar loading point.
3. As disc displacement increases and disc length decreases, AJS increases while SJS and PJS decrease significantly.

4. Tomographic variables appear to be better predictors of disc displacement than disc length in an adolescent population.

The results of this study suggest that joint space and information on the osseous morphology derived from tomographic images may provide diagnostic information for the assessment of joint status in an adolescent population. The clear clinical implication of this study is that one should be cautious about overestimating the significance of radiological abnormality of the condyle and perhaps our attention should be directed to the temporal component of the TMJ in the adolescent population.

Table 3-1 **Method Error as determined through pilot study of 10 joints representative of normal disc position and 10 joints representative of disc displacement. Average, Maximum and Minimum SD Values for Tomographic Variables**

Variable	**Average SD***			**Maximum SD**			**Minimum SD**		
	Overall	Normal	ADD	Overall	Normal	ADD	Overall	Normal	ADD
Anterior joint space (mm)	0.16	0.16	0.17	0.39	0.39	0.34	0.03	0.06	0.03
Posterior joint space (mm)	0.19	0.19	0.19	0.33	0.31	0.35	0.03	0.03	0.03
Superior joint space (mm)	0.24	0.23	0.24	0.40	0.40	0.38	0.05	0.08	0.05
Superior condylar curvature (1/mm)	0.07	0.07	0.08	0.21	0.12	0.21	0.02	0.02	0.03
Central condylar curvature (1/mm)	0.08	0.08	0.08	0.18	0.16	0.20	0.00	0.00	0.00
Inferior condylar curvature (1/mm)	0.08	0.10	0.07	0.19	0.19	0.13	0.02	0.03	0.02
Superior eminence curvature (1/mm)	0.08	0.08	0.08	0.23	0.23	0.19	0.01	0.01	0.03
Central eminence curvature (1/mm)	0.08	0.09	0.07	0.17	0.16	0.16	0.02	0.02	0.03
Inferior eminence curvature (1/mm)	0.07	0.06	0.08	0.14	0.09	0.14	0.02	0.02	0.03

*SD for each radiograph determined over 10 measurements (five tracings of each radiograph measured twice) - Overall SD represents mean of SD's over twenty radiographs. Normal and anterior disc position grouping determined over 10 radiographs. Normal=normal disc position; ADD=anterior disc posiiton.

Table 3 - 2 **Error of Method in Determination of MRI Reference Plane According to Dahlberg Double Determination (n=25)**

Variable	**Error**
MRI eminence reference plane	1.165 degrees

Table 3 - 3 **Reliability of Repeated Measures for Disc Displacement and Disc Length Determination (MRI) as determined from 10 MRI's representative of normal disc position and 10 MRI's representative of disc displacement (n=20)**

Test Variable	**Rel = 1 - 1/F**	**Maximum SD**	**Minimum SD**
Disc displacement (mm)	1.00	0.33	0.05
Disc Length (mm)	0.98	0.47	0.07

Table 3 - 4 Mean, Standard Deviation, Maximum, and Minimum for Entire Study Population (n=335)

Variable	Mean	Std Dev	Minimum	Maximum
AJS (mm)	2.23	0.81	0.75	5.80
PJS (mm)	2.63	0.81	0.64	5.86
SJS (mm)	3.05	0.95	1.18	7.12
Superior condylar curvature (1/mm)	-0.20	0.10	-0.46	0.03
Central condylar curvature (1/mm)	-0.40	0.15	-0.74	0.08
Inferior condylar curvature (1/mm)	-0.04	0.19	-0.55	0.44
Superior eminence curvature (1/mm)	-0.05	0.13	-0.44	0.35
Central eminence curvature (1/mm)	0.08	0.14	-0.32	0.45
Inferior eminence curvature (1/mm)	0.12	0.11	-0.28	0.37
Disc displacement (mm)	1.97	2.67	-3.00	10.05
Disc length (mm)	9.39	2.28	2.38	14.14
Age (months)	13.08	1.94	7.27	20.00

Table 3 - 5 Results of Stepwise Linear Regression for Independent Variables for Overall Sample (n=335) with Dependent Variables of Disc Displacement and Disc Length

Dependent Variable: Disc displacement

Condylar Curvature		
R-Square (adj)	0.04	
Independent Variable	**Coefficient**	**p-value**
Superior	-5.497096	0.0002
Constant	0.872449	0.0078

Eminence Curvature		
R-Square (adj)	0.27	
Independent Variable	**Coefficient**	**p-value**
Superior	-5.2449	<0.0001
Central	-5.0666	<0.0001
Inferior	-2.9694	0.0351
Constant	2.4441	<0.0001

Joint Space		
R-Square (adj)	0.36	
Independent Variable	**Coefficient**	**p-value**
AJS	1.404195	<0.0001
PJS	0.7823	<0.0001
SJS	-1.5854	<0.0001
Constant	1.6182	0.0044

Overall Regression		
R-Square (adj)	0.42	
Independent Variable	**Coefficient**	**p-value**
AJS	1.228320	<0.0001
PJS	0.569225	0.0015
SJS	-1.077933	<0.0001
Central em. Curvature	-2.657379	0.0138
Inferior em. Curvature	-3.021096	0.0167
Gender	-0.911292	<0.0001
Constant	1.963851	0.0003

Dependent Variable: Disc length

Condylar Curvature		
R-Square (adj)	0.02	
Independent Variable	**Coefficient**	**p-value**
Central	-2.365666	0.0039
Constant	8.456	<0.0001

Eminence Curvature		
R-Square (adj)	0.20	
Independent Variable	**Coefficient**	**p-value**
Superior	2.409165	0.0203
Central	4.117752	0.0002
Inferior	3.228625	0.0108
Constant	8.807677	<0.0001

Joint Space		
R-Square (adj)	0.23	
Independent Variable	**Coefficient**	**p-value**
AJS	-0.619805	<0.0001
PJS	-0.773366	<0.0001
SJS	1.329192	<0.0001
Constant	8.75527	<0.0001

Overall Regression		
R-Square (adj)	0.27	
Independent Variable	**Coefficient**	**p-value**
AJS	-0.473987	0.0008
PJS	-0.595593	0.0005
SJS	0.924456	<0.0001
Central em. curvature	2.263988	0.0285
Inferior em. curvature	2.797172	0.0207
Gender	0.494131	0.0282
Constant	8.481209	<0.0001

Table 3 - 6 Mean, Standard Deviation, Maximum, and Minimum for Male Study Population (n=134)

Variable	Mean	Std Dev	Minimum	Maximum
AJS (mm)	2.20	0.85	0.75	5.80
PJS (mm)	2.74	0.86	0.64	5.86
SJS (mm)	3.32	0.97	1.18	7.12
Superior condylar curvature (1/mm)	-0.19	0.10	-0.46	0.03
Central condylar curvature (1/mm)	-0.4	0.15	-0.72	-0.02
Inferior condylar curvature (1/mm)	-0.04	0.20	-0.55	0.44
Superior eminence curvature (1/mm)	-0.04	0.13	-0.37	0.27
Central eminence curvature (1/mm)	0.11	0.13	-0.32	0.41
Inferior eminence curvature (1/mm)	0.13	0.10	-0.28	0.37
Disc displacement (mm)	1.04	2.16	-3.00	10.03
Disc length (mm)	9.99	1.93	3.46	13.76
Age (months)	13.02	1.96	7.27	17.09

Table 3 - 7 Results of Stepwise Linear Regression for Independent Variables for Male Sample (n=134) with Dependent Variables of Disc Displacement and Disc Length

Dependent Variable: Disc displacement

Condylar Curvature

R-Square (adj) 0.05

Independent Variable	**Coefficient**	**p-value**
Superior	-4.121988	0.0113
Constant	0.508692	0.138

Eminence Curvature

R-Square (adj) 0.23

Independent Variable	**Coefficient**	**p-value**
Central	-7.424914	<0.0001
Constant	2.076854	<0.0001

Joint Space

R-Square (adj) 0.35

Independent Variable	**Coefficient**	**p-value**
SJS	-0.902513	<0.0001
AJS	1.115306	<0.0001
PJS	0.502991	0.0176
Constant	0.441652	0.5097

Overall Regression

R-Square (adj) 0.41

Independent Variable	**Coefficient**	**p-value**
SJS	-0.610321	<0.0001
AJS	1.076501	<0.0001
PJS	0.476139	0.0323
Central em. curvature	-3.350052	0.0177
Constant	0..646633	0.3549

Dependent Variable: Disc length

Condylar Curvature

No significant variables

Eminence Curvature

R-Square (adj) 0.11

Independent Variable	**Coefficient**	**p-value**
Central	4.949255	<0.0001
Constant	9.45729	<0.0001

Joint Space

R-Square (adj) 0.16

Independent Variable	**Coefficient**	**p-value**
SJS	0.645426	<0.0001
AJS	-0.482841	0.0093
Constant	8.91182	<0.0001

Overall Regression

R-Square (adj) 0.16

Independent Variable	**Coefficient**	**p-value**
SJS	0.645426	<0.0001
AJS	-0.482841	0.0093
Constant	8.91182	<0.0001

Table 3 - 8 Mean, Standard Deviation, Maximum, and Minimum for Female Study Population (n=201)

Variable	Mean	Std Dev	Minimum	Maximum
AJS (mm)	2.24	0.79	0.87	4.69
PJS (mm)	2.56	0.78	0.75	5.35
SJS (mm)	2.87	0.89	1.29	6.45
Superior condylar curvature (1/mm)	-0.21	0.09	-0.46	-0.01
Central condylar curvature (1/mm)	-0.39	0.15	-0.74	0.08
Inferior condylar curvature (1/mm)	-0.04	0.19	-0.52	0.37
Superior eminence curvature (1/mm)	-0.07	0.13	-0.44	0.35
Central eminence curvature (1/mm)	0.06	0.14	-0.29	0.45
Inferior eminence curvature (1/mm)	0.11	0.11	-0.24	0.34
Disc displacement (mm)	2.59	2.80	-1.47	10.05
Disc length (mm)	9.00	2.41	2.38	14.14
Age (months)	13.12	1.92	9.05	20.00

P

Table 3 - 9 Results of Stepwise Linear Regression for Independent Variables for Female Sample (n=201) with Dependent Variables of Disc Displacement and Disc Length

Dependent Variable: Disc displacement

Condylar Curvature

No Significant Variables

Eminence Curvature

R-Square (adj)	0.24	
Independent Variable	**Coefficient**	**p-value**
Superior	-4.647547	0.0036
Central	-3.230536	0.0444
Inferior	-4.910747	0.0143
Constant	3.048216	<0.0001

Joint Space

R-Square (adj)	0.33	
Independent Variable	**Coefficient**	**p-value**
SJS	-1.680943	<0.0001
PJS	0.964591	0.0001
AJS	1.485345	<0.0001
Constant	1.648826	0.0280

Overall Regression

R-Square (adj)	0.38	
Independent Variable	**Coefficient**	**p-value**
SJS	-1.26626	<0.0001
PJS	0.671149	0.0090
AJS	1.454928	<0.0001
Inferior em. curvature	-7.013998	<0.0001
Constant	2.035473	0.0084

Dependent Variable: Disc length

Condylar Curvature

R-Square (adj)	0.03	
Independent Variable	**Coefficient**	**p-value**
Central	-2.657336	0.0163
Constant	7.984501	<0.0001

Eminence Curvature

R-Square (adj)	0.22	
Independent Variable	**Coefficient**	**p-value**
Superior	2.868855	0.0470
Central	2.978888	0.0415
Inferior	5.223572	0.0043
Constant	8.453472	<0.0001

Joint Space

R-Square (adj)	0.24	
Independent Variable	**Coefficient**	**p-value**
SJS	1.55098	<0.0001
PJS	-1.012293	<0.0001
AJS	-0.672699	0.0006
Constant	8.662464	<0.0001

Overall Regression

R-Square (adj)	0.32	
Independent Variable	**Coefficient**	**p-value**
SJS	1.194778	<0.0001
PJS	-0.758498	0.0013
AJS	-0.602846	0..0015
Inferior em. curvature	5.792914	<0.0001
Age	-0.164691	0.0206
Constant	10.529350	<0.0001

Figure 3-1 **Posterior slope of the articular eminence**

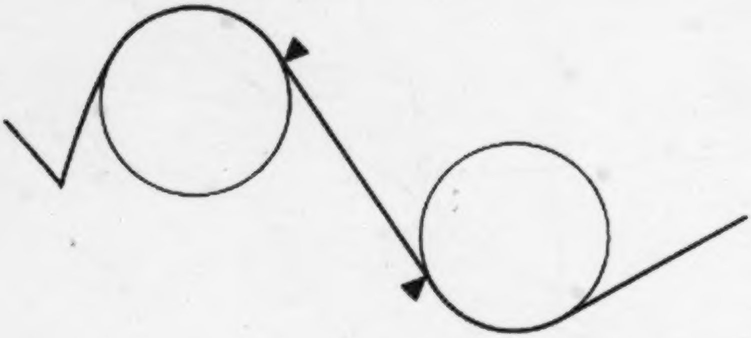


Figure 3-2 **Geometrical relationships in calculation of loading distance; Condylar Load Point (CLP), Anterior Joint Space (AJS)**

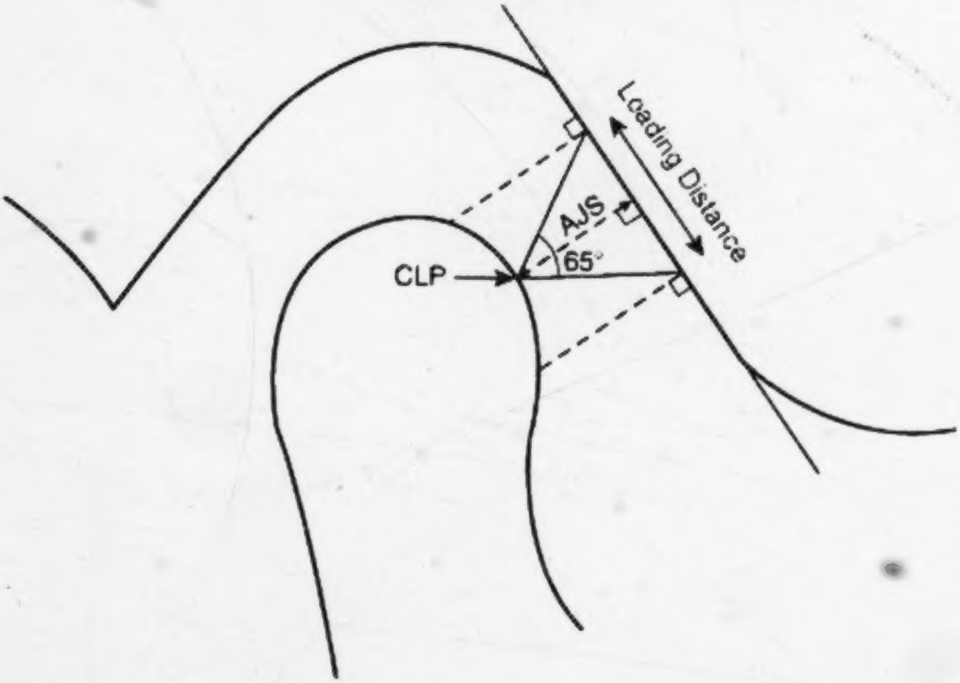

Loading Distance
AJS
65°
CLP

Figure 3-3 Delineation of overall, superior, central, and inferior sectors of loading surface

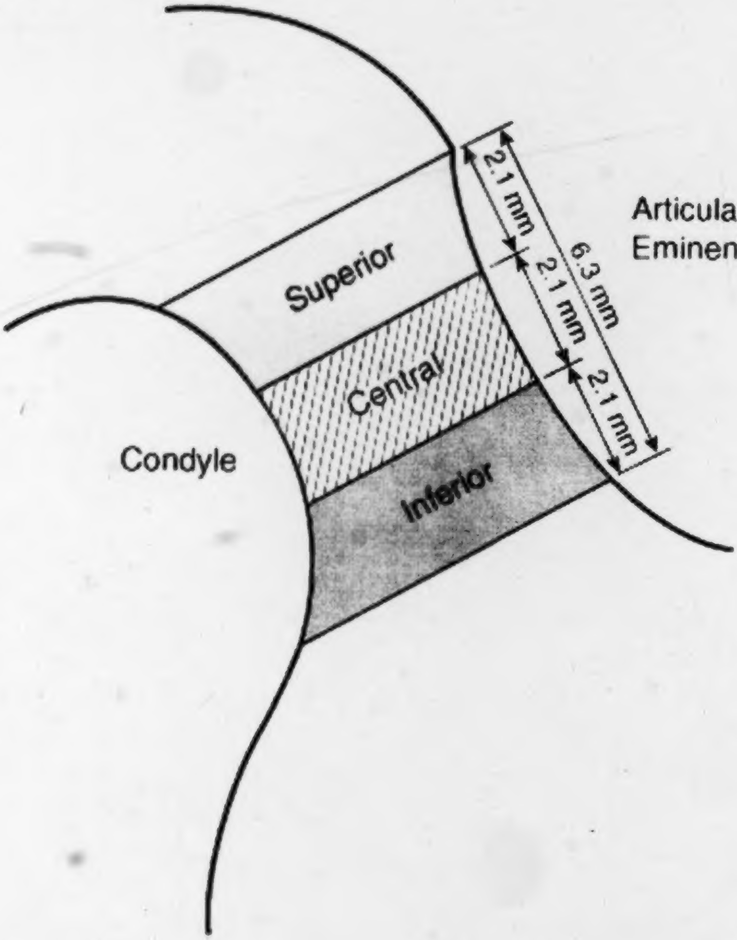

Articular Eminence
2.1 mm
6.3 mm
2.1 mm
2.1 mm
Superior
Central
Inferior
Condyle

Figure 3-4 Locations of measurements of closest anterior (A), posterior (P) and superior (S) interarticular spaces in temporomandibular joint tomograms

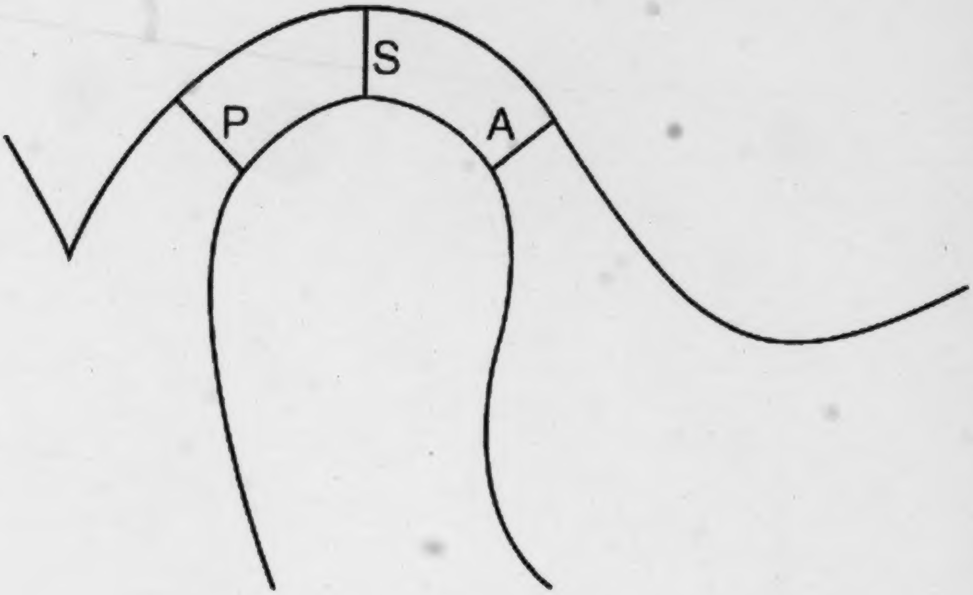


Figure 3 - 5 **Establishment of Plane for Quantitative Assessment; FH - Frankfort horizontal; ERP - eminence reference plane**

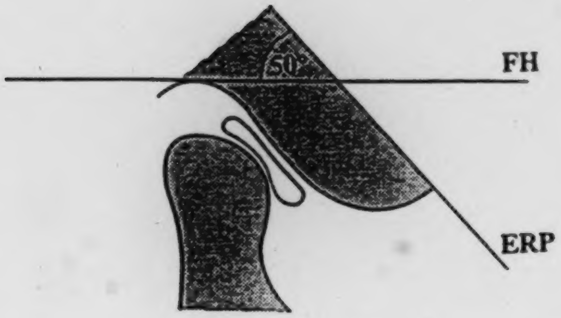
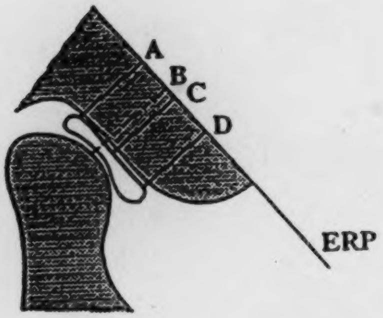


Figure 3 - 6 **Reference Points for Disc Length and Disc Displacement Determination: A - posterior band; B - condylar load point; C - midpoint of disc; D - anterior band**



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Chapter Four

Discussion and Recommendations

4.1 - General Discussion

The relationship between the soft and osseous tissues of the temporomandibular joint has been studied radiographically, through autopsy, and in surgical specimens. Since the imaging of the osseous tissues of the temporomandibular joint is less invasive and expensive than arthrography, and more readily available than magnetic resonance imaging, the identification of characteristics in tomographic images of the temporomandibular joint which may suggest soft tissue disturbances would be of significant value to the dental community. Given the number of potential asymptomatic patients with internal derangement[1-4], an aid which enables the identification of these patients would be beneficial. Tomography may provide a valuable resource in this area. The challenge is to determine if there are characteristics which are associated with soft tissue abnormalities, and if there is, are they sequelae or anatomical predisposing factors to internal derangement.

Existing research has examined the relationship of the osseous morphology of the TMJ to that of disc position and deformation. The majority of this research has been conducted on adult populations and has limited the examination of osseous changes through subjective evaluation of radiographic images, surgical findings or autopsy specimens. The purpose of this study was to further investigate the differences in the spatial and structural relationships of the osseous components of the temporomandibular joint for those with normal and anterior disc position in an adolescent population. It was also the aim of this study to assess the capability of osseous characteristics identified in tomographic images to predict disc displacement and disc deformation in a pre-orthodontic adolescent population. This information is of special interest to the orthodontic community given their target treatment population.

The first part of this study consisted of a direct comparison of the positional and structural relationships of the osseous components of the temporomandibular joint between subjects with normal superior disc position and those with an anterior disc position. Although previous studies have used a variety of subjective and objective measures to identify osseous characteristics, this study attempted to delineate a non-arbitrary reference system based upon a biomechanical loading model of the temporomandibular joint[5]. The use of the posterior slope of the articular eminence as reference plane prevents the use of cranial and dental reference planes which must be extrapolated to films or assumed to be existent. The development of a standardized loading distance for the entire population allows for between patient comparison. Without such standardization the arbitrary selection of reference points given the tremendous range of temporal and condylar morphology would make the results of this study untenable.

Results from the first part of the study revealed that temporomandibular joints with normal disc position and those with anterior disc position differ significantly with respect to joint space, condylar position, and morphology of the articular eminence for both males and females. Anterior, superior, and posterior joint spaces were significantly different for normal and anterior disc position in females while only anterior and superior joint spaces were significantly different for the male population. Similar findings have been reported elsewhere in the literature utilizing different methodology and a primarily adult population[6-8]. Comparison between studies is difficult due to differences in investigative techniques and sampling, but from the examination of the absolute values given by Ren et al.[7] for anterior joint space, posterior joint space, and condylar position it would appear that adolescents have more anteriorly positioned condyles, smaller anterior joint space and similar posterior joint space dimensions in the normal and anterior disc position subjects than the adult population. This would agree with the observations of Cohlmia et al.[9] for condylar position, although no effort was made to classify disc position in the aforementioned study.

Measures of eminence curvature revealed a statistically significant reduction in the convexity of the posterior slope of the eminence for those with anterior disc position. This alteration in the morphology of the eminence with anterior disc displacement is similar to the findings of Panmekiate et al.[10]. Their findings indicate that the posterior slope of the articular eminence is less prominent in those with ADD without reduction than in normal and reducing joints as visualized on arthrograms. Ren et al.[11] found that the angle of the posterior slope of the articular eminence was reduced in 71 patients with internal derangement as diagnosed with dual space arthrography in comparison to 34 asymptomatic volunteers. De Bont et al.[12] found that degenerative changes of the eminence often precede those of the condyle and the steepness of the eminence decreases with the severity of disc displacement in a light microscopic study of 22 specimens.

The reduction in convexity of the posterior slope of the eminence could be explained by positional changes of the condyle within the fossa, regressive remodeling, or differences in the growth pattern with disc displacement for the eminence in this adolescent population. For positional changes, the reduced superior joint space would dictate that in the absence of osseous deposition in the height of the mandibular fossa, the condyle occupies a more superior position within the fossa. As the condylar load point moves further superiorly, the convexity of the opposing posterior slope of the articular eminence would decrease.

The elastic modulus of the TMJ disc is much less than those of bony structures, thus confirming the role of the disc in absorbing stresses acting at the bony surfaces of the TMJ[13]. Nickel and McLachlan[14] found that the disc reduces the load by about half. Thus, in the absence of the disc, force levels will be significantly increased. Copray[15] has shown that the articular tissues of the condyle and eminence are able to withstand and grow under heavy intermittent forces up to a particular threshold in rats. Once the force threshold is reached, growth will cease. Growth in the size of the joint appears to cease, at least in the condyle, by late teens or early twenties[16] and at a similar time for the temporal component. Applied to the adolescent population in this study, the displacement of the disc may increase the force levels which the articular tissues of the condyle and eminence must endure. In some instances, the optimal level of mechanical stimulation required by the articular eminence for continued growth may be exceeded[17,18]. With either continued growth of the eminence in those subjects with normal disc position, or regressive remodeling of the posterior slope in those with disc displacement due to excessive force[19,20], the different temporal osseous component convexities would become evident.

Emphasis on the apparent differences in convexity of the posterior slope of the articular eminence between those with disc displacement and those without should be interpreted with caution. Flygare et al.[21] examined 40 TMJ's taken from autopsy specimens with an average age of 75 years. No indication of disc position was given. Tomographic images of the specimens were taken to examine the radiographic appearance of erosions and were then verified by microscopic and macroscopic examination. For the temporal component, there was a high incidence of false positive radiologic diagnoses as hard tissue changes were masked macroscopically by the presence of an intact articular surface, similar to the findings of other authors[22-27]. In addition, the contour of the osseous structures of the articular eminence may not be predictive of the overlying articular soft tissue[28,29].

For the adolescent population represented in this study, there was no significant difference in condylar osseous morphology for those subjects with normal disc position and those with anterior disc position. Findings in contrast to this in the literature may be explained by numerous factors. Differences in the age range of the sample, imaging modalities used, means of evaluating disc position, and means of assessing condylar morphology may all contribute to the observed differences in findings. Degenerative changes of the condyle do appear to be more prevalent in the adult population[30,31]. An autopsy study[22] indicated that of the 13 TMJ's under 20 years of age examined, all revealed smooth and unaffected surfaces of the condyle and eminence with no evidence of arthrosis, although no indication of disc status was given. It is possible that because of the differences at the cellular level between growing individuals and adults[25,32,33] the condylar surfaces of the adolescent may react differently to differences in disc displacement and loading than the adult population. Thus, the adaptive potential of the growing condyle may be better suited to the changes in stress distribution throughout the range of disc displacement.

Alternatively, changes that may occur in the adolescent condyle with disc displacement could be masked by the reference system, soft tissue, or may be qualitative rather than quantitative in nature. The examination of only the anterosuperior surface of the condyle neglects the examination of the posterior, superior, medial, and lateral surfaces of the condyle which are also subject to potential compressive and tensile stress during function[34]. Lubsen et al.[25] and Stegenga et al.[35] have suggested that condylar changes are initiated by alterations in the cartilage and that it is not unreasonable that the radiographic changes associated with this may not be evident in the early stages. As a result, the osseous manifestations of remodeling may not yet be evident in this young patient population. Qualitative changes in the architecture of the osseous tissue would not be identified in this study. Changes in trabecular pattern[36], subchondral sclerosis, condylar flattening, osteophyte formation, lipping, erosions, or the formation of a cyst with the breakdown of subchondral bone may all be verified with subjective examination of images and may not be apparent with the reference system utilized in this study.

Inherent limitations in the measurement design of tomographic variables and application of the reference system were encountered. The standardization of the loading distance was set at 6.3 mm based upon average anterior joint space for a sample of subjects with anterior disc position in a static force system. In reality, the variability of such a force system is extremely high and is dependent upon factors such as muscle force, muscle vector, muscle recruitment patterns, angle of the articular eminence, angle of the occlusal plane, point of bite force application, centric clenching or mediolateral excursions, and craniofacial structure[34,38-41]. In addition, the variables which may influence each of these factors are numerous and to calculate a three dimensional loading pattern for each subject is beyond the scope of this study. The use of the closest anterior joint space is presumed to correspond to the central load bearing portion of the disc except in cases of disc displacement[42]. The standardization of the loading distance and condylar loading point was to allow for a method of between patient comparison and is no way meant to infer that all condylar loading occurs within a 6.3 mm distance apposed to the posterior slope of the articular eminence during maximum intercuspation.

The role of variables such as malocclusion, skeletal asymmetry, growth direction, or seasonal growth were not assessed in this study. Research has indicated that these factors may play a role in joint space measurements and the contours of the osseous structures of the temporomandibular joint [7,43-47]. Patient clenching in the bite registration material during imaging could also have an effect on joint space measures[48]. Furthermore, the potential impact of soft tissue thickness and subsequent role in the perceived impression of joint space must be considered. It has been suggested[26,27] that the osseous contours seen on radiographs may not accurately predict the actual articular surface of the temporal and condylar component of the temporomandibular joint and that soft tissue may compensate for osseous abnormalities of the joint. This may have significant implications in the interpretation of joint space if the potential range of soft tissue from 1.5 mm at the articular eminence in addition to a potential 1.0 mm on the condylar head[28,49] is considered. In addition, the ability to predict the thickness or contour of the soft tissue from the osseous contour is poor[28,49,50].

Tomographs were only utilized from the central slice in the sagittal plane in order to maintain consistency with the loading model utilized in this study. Research indicates that joint space dimensions and osseous contours are not consistent in the medial, central and lateral component of the joint[51,52]. The selection of only the central slice may not accurately represent the position of the condyle within the fossa or the contours of the osseous structures. Future expression of condylar position and osseous morphology might utilize three dimensional imaging or a greater number of tomographic sections. With respect to measurement of osseous morphology, this may require modification of the reference system used in this study as loading patterns have been shown to vary in medial, central, and lateral portions of the TMJ[34].

A weakness of this study involves the definition of subjective anterior disc position. In an effort to increase sample sizes, the criteria for inclusion in this category did not include a disc classification of reducing, non-reducing, or description of perforation. Non-reducing discs and those with perforation have been shown to be associated with an increased frequency of structural and hard tissue changes in comparison to subjects diagnosed with anterior disc displacement with reduction[8,53-55].

All measurements of tomographic variables were made by the same investigator. Inter-examiner reliability tests for potential error in the location of critical reference points was not undertaken in this study. Patient positioning errors may have influenced the measurement of joint space[56] although a study by Kamelchuk et al.[57] has shown that a ten degree rotation will not influence joint space measurements significantly.

The purpose of the second portion of this study was to determine if temporomandibular disc displacement and deformation, as identified on magnetic resonance images, can be associated with specific positional and morphological characteristics of the osseous components of the temporomandibular joint, as viewed in axially corrected tomographs of an adolescent sample. In comparison to previous studies which have examined condylar position and osseous changes in relation to categorical descriptions of disc position and configuration [6-8,10,11,53,54,58,59], this study utilized a continuous data set for the assessment of joint status. This offers the distinct advantage of enabling the investigator to utilize a greater amount of information from a given sample population. This unique method of disc assessment was developed by Nebbe et al.[60] and the absolute values of disc displacement and disc length provided by these investigators for this sample was used in this study.

Because of the differences in the collection of joint status data and methods of statistical analysis with this study and previous studies[6-8,10,11,53,54,58,59], direct comparison of results is difficult. For the combined sample and inclusion of all independent variables, gender had a significant association with disc length and disc displacement. This finding would agree with those in the literature who have suggested a predominance of females in populations with TMD[61-64], and those who have found a predominance of females with disc displacement in other populations[30]. The significance of this finding should be interpreted with caution since this is not a random sample and may not be truly representative of the respective population.

Measures of condylar curvature indicated a weak association with disc length and disc displacement. R-square values were low (0.02 to .05). Given the result of the first part of this study and the poor predictive value of condylar curvature variables in the assessment of joint status for the second portion of the study, it would appear that disc displacement and disc length cannot be determined through the examination of the anterosuperior curvature of the condyle in this sample.

When measures of eminence curvature were considered as a distinct group, all three curvatures had a significant association with disc length and displacement, with the exception of the male population where only the central eminence curvature had a significant association. The curvature of the posterior slope of the eminence would become less protuberant with increasing disc displacement and deformation. Possible explanations for this finding have been previously discussed. The value of the significance using this continuous data set may indicate that these changes are progressive throughout the continuous range of displacement rather than being limited to those with non-reducing or perforated discs[8,53-55].

Although previous researchers have negated the predictive value of joint space in for internal derangement due to the high variability[7,65-67], R-square values for joint space were the highest in relation to condylar curvature and eminence curvature for each sample and measure of joint status evaluated. Although not diagnostic, these results would imply that measures of joint space may be suggestive of disc displacement and deformation in an adolescent population.

The variable of age had a significant negative association with only disc length in the female population. This would agree with the correlation coefficient for disc length and age in the female sample which was -0.16 with a p-value of .02. This would indicate that as age increases in the female sample, disc length is reduced. This could be interpreted as long standing displacement is necessary in the female population for disc deformation to become apparent[68]. In addition, the possible greater maturity of the female articular tissue in relation to the male may make it less adaptive to changes in position that may occur with age[69].

The limitations and potential sources of error discussed with respect to the first portion of the study also apply to the this section. Given that this sample is not randomly selected, the results obtained may not be truly representative of the population.

The sample in this study was representative of the Western Canadian pre-orthodontic adolescent population and control of potential age, racial variations, or relative patient size for the investigated variables were not factored into the study[70].

4.2 - Clinical Implications

With respect to how this information on joint space dimensions and condylar position in those with and without internal derangement can be applied to clinical orthodontics, one must consider the changes that are made with respect to the relative condylar position with treatment. Although an effort has been made by previous researchers to show that orthodontic treatment does not have a significant effect on condylar position[71-73], recent evidence suggests that orthodontic treatment may have a significant effect on joint space dimensions and condylar position[44,74]. Normalization of condylar position through expansion and relief of unilateral crossbites would appear to be favorable in terms of condylar loading and future growth[44]. The potential alteration of condylar position and joint space with fixed appliances during adolescence is unlikely to induce temporomandibular disorders[75]. The increased cellularity and adaptive potential of the adolescent neuromuscular, skeletal, and articulating tissues may allow for suitable adaptation to changes in the temporomandibular joint. Longitudinal studies utilizing MRI for assessment of disc position and deformation during orthodontic treatment would be necessary to assess this further.

The current data supports the view that internal derangement constitutes a particular risk for development of structural hard tissue changes in the temporomandibular joint. Degeneration or remodeling of joint components other than the disc may only be an accompanying feature of abnormal disc position[12,53], but could be considered a predisposing factor[35]. Until further longitudinal studies are conducted, the definitive answer to this question remains unresolved. Because of this, it would be prudent of the dentist to identify patients clinically and radiographically with risk factors suggestive of internal derangement. Although the adaptive capacity of the adolescent patient may be high, the ability to predict those patients whose functional capacity is reduced because of aging or internal derangement is not. This must be taken into account when our treatment modalities and the potential implication they may have on joint loading through alteration of anatomical relationships, force directions, or force magnitude are chosen.

4.3- Recommendations for future studies

Continued research is necessary in the area of temporomandibular joint disorders for the adolescent population in order to determine possible predisposing factors, sequelae, and implications on orthodontic treatment. The following is a list of factors to consider in future studies which may reduce the potential weaknesses and provide further insight into this area of research:

1. Inter-examiner reliability of tomographic measures of osseous morphology should be assessed.
2. A larger overall sample size may allow for the categorization of anteriorly displaced discs into reducing, non-reducing, perforated, or non-perforated discs. In addition, variables such as race, craniofacial structure, growth

direction, asymmetries, skeletal age and malocclusion may be utilized with a larger sample while maintaining statistical power.

3. The change in the morphologic position of the condylar loading point may occur through physiologic remodeling of the loading surface, rotation of the condyle secondary to growth or altered vertical dimension with prosthetics, orthodontic treatment, or orthognathic surgery. For this reason, the reference system utilized in this study for assessment of condylar and eminence morphology will not maintain validity in a longitudinal study. The determination of stable anatomic landmarks in tomographic images of the temporomandibular fossa would allow the establishment of an anatomical reference plane which could be used in longitudinal studies as well as throughout the entire mediolateral dimension of the joint.
4. Radiographs utilized in this study were taken with the teeth in maximum intercuspation. Thus, the position of the condyle in the fossa was influenced by the occlusion. Although unrealistic, the utilization of splint therapy prior to imaging would allow for the determination of a true anatomical position of the condyle in the fossa as dictated by the temporomandibular soft tissues and musculature.
5. Future studies investigating the impact of growth, orthopedic forces, and orthodontic treatment on temporomandibular joint morphology and positional relationships must consider the categorization of subjects by disc position and disc deformation.

6. Three dimensional reconstruction of the mandibular condyle would allow for condyle position and temporomandibular joint morphology in relation to disc status to be assessed throughout the entire joint.

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Appendix

Variable	SJS	PJS	Sup Cond	Cent Cond	Inf Cond	Sup Em	Cent Em	Inf Em	Displacement	Disc Length	Age	Gender
AJS	0.01 P= .811	-0.13 P= .018	-0.22 P<.0001	-0.11 P= .050	0.20 P<.0001	-0.25 P<.0001	-0.22 P<.0001	-0.06 P= .261	0.39 P<.0001	-0.18 P= .001	0.17 P= .002	-0.03 P= .598
SJS		0.60 P<.0001	0.17 P= .001	-0.21 P<.0001	0.16 P= .003	0.57 P<.0001	0.46 P<.0001	0.32 P<.0001	-0.42 P<.0001	0.39 P<.0001	0.12 P= .030	0.23 P<.0001
PJS			0.09 P= .088	-0.04 P= .458	0.01 P= .845	0.33 P<.0001	0.16 P= .003	0.08 P= .156	-0.15 P= .005	0.08 P= .124	0.08 P= .149	0.11 P= .049
Sup Cond				-0.10 P= .064	0.15 P= .008	0.31 P<.0001	0.22 P<.0001	0.18 P= .001	-0.20 P<.0001	0.11 P= .050	-0.10 P= .077	0.11 P= .041
Cent Cond					-0.69 P<.0001	-0.14 P= .009	-0.21 P<.0001	-0.30 P<.0001	0.10 P= .058	-0.16 P= .004	0.01 P= .787	-0.04 P= .444
Inf Cond						0.11 P= .047	0.18 P= .001	0.39 P<.0001	-0.07 P= .188	0.09 P= .084	-0.07 P= .226	0.01 P= .803
Sup Em							0.52 P<.0001	0.32 P<.0001	-0.43 P<.0001	0.32 P<.0001	0.07 P= .193	0.11 P= .048
Cent Em								0.56 P<.0001	-0.46 P<.0001	0.41 P<.0001	-0.03 P= .607	0.17 P= .002
Inf Em									-0.35 P<.0001	0.34 P<.0001	-0.08 P= .150	0.10 P= .072
Disc Displacement										-0.69 P<.0001	0.08 P= .155	-0.28 P<.0001
Disc Length											-0.06 P= .252	0.21 P<.0001
Age												-0.03 P= .632

Correlation Coefficients of Age, Gender, Tomographic, and MRI Variable for Entire Study Population (n=335)

Variable	SJS	PJS	Sup Cond	Cent Cond	Inf Cond	Sup Em	Cent Em	Inf Em	Displacement	Disc Length	Age
AJS	-0.05 P= .585	-0.13 P= .125	-0.13 P= .131	-0.09 P= .317	0.13 P= .137	-0.32 P<.0001	-0.32 P<.0001	-0.13 P= .126	0.48 P<.0001	-0.23 P= .008	0.29 P= .001
SJS		0.63 P<.0001	0.32 P<.0001	-0.20 P= .020	0.09 P= .325	0.55 P<.0001	0.50 P<.0001	0.21 P= .017	-0.40 P<.0001	0.33 P<.0001	0.13 P= .144
PJS			0.10 P= .274	-0.06 P= .502	-0.02 P= .831	0.22 P= .012	0.25 P= .004	0.06 P= .500	-0.16 P= .058	0.11 P= .194	0.04 P= .625
Sup Cond				-0.19 P= .032	0.23 P= .009	0.43 P<.0001	0.34 P<.0001	0.17 P= .052	-0.23 P= .006	0.09 P= .281	-0.09 P= .292
Cent Cond					-0.71 P<.0001	-0.10 P= .230	-0.29 P= .001	-0.24 P= .006	0.13 P= .129	-0.14 P= .113	-0.01 P= .909
Inf Cond						0.04 P= .626	0.23 P= .007	0.39 P<.0001	-0.04 P= .641	0.02 P= .863	-0.09 P= .297
Sup Em							0.48 P<.0001	0.07 P= .425	-0.40 P<.0001	0.20 P= .021	0.15 P= .082
Cent Em								0.41 P<.0001	-0.48 P<.0001	0.33 P<.0001	0.06 P= .515
Inf Em									-0.17 P= .045	0.13 P= .139	-0.06 P= .478
Disc Displacement										-0.62 P<.0001	-0.03 P= .727
Disc Length											0.11 P= .213

Correlation Coefficients of Age, Gender, Tomographic, and MRI Variables for Male Study Population (n=134)

Variable	SJS	PJS	Sup Cond	Cent Cond	Inf Cond	Sup Em	Cent Em	Inf Em	Displacement	Disc Length	Age
AJS	0.07 P= .302	-0.12 P= .086	-0.28 P<.0001	-0.12 P= .081	0.25 P<.0001	-0.21 P= .003	-0.15 P= .029	-0.01 P= .897	0.36 P<.0001	-0.15 P= .036	0.08 P= .256
SJS		0.57 P<.0001	0.02 P= .759	-0.21 P= .002	0.22 P= .002	0.57 P<.0001	0.40 P<.0001	0.37 P<.0001	-0.37 P<.0001	0.37 P<.0001	0.13 P= .067
PJS			0.07 P= .312	-0.02 P= .770	0.03 P= .673	0.40 P<.0001	0.08 P= .251	0.07 P= .294	-0.11 P= .108	0.04 P= .622	0.11 P= .112
Sup Cond				-0.03 P= .638	0.08 P= .231	0.21 P= .003	0.12 P= .090	0.17 P= .013	-0.15 P= .035	0.08 P= .244	-0.10 P= .171
Cent Cond					-0.67 P<.0001	-0.16 P= .021	-0.16 P= .028	-0.34 P<.0001	0.08 P= .269	-0.16 P= .023	0.03 P= .678
Inf Cond						0.15 P= .032	0.14 P= .043	0.38 P<.0001	-0.09 P= .216	0.14 P= .053	-0.05 P= .489
Sup Em							0.54 P<.0001	0.46 P<.0001	-0.43 P<.0001	0.36 P<.0001	0.02 P= .750
Cent Em								0.64 P<.0001	-0.42 P<.0001	0.41 P<.0001	-0.07 P= .305
Inf Em									-0.42 P<.0001	0.43 P<.0001	-0.09 P= .224
Disc Displacement										-0.69 P<.0001	0.13 P= .069
Disc Length											-0.15 P= .034

Correlation Coefficients of Age, Gender, Tomographic, and MRI Variable for Female Study Population (n=201)